INDIVIDUAL VARIATIONS IN THE METABOLIC COST OF HUMAN ACTIVITIES

K. MAHADEVA
L.M.S. Ceylon, D.T.M.& H. Edin.

(Dept. of Public Health & Social
Medicine and Dept. of Physiology,
University of Edinburgh.)

Thesis presented for the Degree
of Doctor of Philosophy,
University of Edinburgh
1953

TABLE OF CONTENTS

Note

The complexity of modern experimental work in medical research makes it difficult to find a subject which a Ph.D. candidate can undertake alone. In this thesis the author is solely responsible for Parts I and IV. Part II is an account of a joint investigation with Dr. B. Woolf and myself. Part III contains an account of a survey carried out by a team of investigators from the Departments of Physiology in the Universities of Edinburgh and Glasgow under the auspices of the Medical Research Council. In this survey Mr. Mahadeva carried out a major part of the laboratory analyses and is entirely responsible for the statistical treatment of the data.

R. Passmore
Supervisor.

GENERAL INTRODUCTION

A scientific discovery is often not the work of a single person at a definite time. Frequently evidence contributed by different people working at different times and places accumulates and finally convinces. The science of nutrition has advanced in this manner. Throughout its progressive history contributions have come from people from many walks of life, including physicians, chemists, agriculturists, sailors and several others.

By the end of the nineteenth century many far reaching advances had been made. The researches were mainly individual projects. The energy aspect of nutrition and the functioning of the body as a machine were well recognised concepts and accurate methods had been developed for measuring energy expenditure in people of different size, age and activity. Much information had also been gathered about the protein, fat and carbohydrate contents and the energy values of foods and of dietaries. The discovery of accessory food factors by Professor Frederick Gowland Hopkins in the early part of this century initiated the age of vitamins and was an important milestone in the progress of nutrition. This discovery served to intensify research on vitamins and for a period of four decades there was almost a standstill in the further development of the energy aspect of nutrition.

The second world war brought in its wake a multitude of nutritional problems caused by food crises, famine and starvation. During recent years the peoples of the world have fast been becoming conscious of the importance of health. There has been also developing a spirit of international ~~service in world opinion~~ co-operation resulting in several international projects. Thus the founders of the Food and Agricultural Organisation of the United Nations (F.A.O.) believed that freedom from want could be achieved. Their second world food survey (1952) concludes, "In the last few years, consciousness that the world is one has grown apace. There is increasing realisation that the better-off countries must assist the comparatively poorer nations, not merely from humanitarian motives, but also to safeguard their own living standards. There is also a greater understanding, which in some degree is already being translated into action, of the need for integrated planning at all levels to achieve higher living standards for people all over the world. But, as this report has emphasized throughout, actual achievement is still all too meagre."

For this, periodic appraisals of the world situation are necessary, in which estimates of the food supplies of countries are compared with the needs of their population. The F.A.O. report on Calorie Requirements (1950) provided a provisional yard-stick of human Calorie needs. Their system of assessing Calorie requirements is relatively simple and built on knowledge, part of which is based on extensive data and part on a very limited experimental and observational background. The report draws attention to several gaps in fundamental physiological knowledge, all of which have a bearing on the validity of their recommendations. The investigations reported here follow the line of their policy and the problem chosen is the study of energy expenditure of individuals of different types engaged in various activities. The thesis is divided into four main sections:-

I. A historical survey of the development of metabolic measurements.

II. The individual variations in the metabolic cost of standardised human activities.

III. The variations in the metabolic cost of various activities of coal miners and clerks.

IV. The energy expenditure at rest of Southern Asiatics resident in Britain.

PART I

HISTORICAL SURVEY

Early researches

What becomes of the food eaten was a problem that aroused interest early in historical times. This problem was considered by Hippocrates, the famous priest of Aescupalius, officiating in the celebrated Health Temple of Cos in Greece, who by his wisdom and skill earned the title of Father of Medicine (Adams, 1891). In Aphorism 13 he states, "old persons endure fasting more easily; next, adults; young persons not nearly so well; and most especially infants, and of them such as are of a particularly lively spirit". Aphorism 14 reads, "Growing bodies have the most innate heat; they therefore require the most food, for otherwise their bodies are wasted. In old persons the heat is feeble, and therefore they require little fuel, as it were, to the flame, for it would be extinguished by much. On this account, also, fever in old persons are not equally acute, because their bodies are cold."

Air is essential to life

The Honourable Robert Boyle (1772), the seventh son of the Earl of Cork, investigated the properties of air and showed the dependence of animals upon the air which they breathe for life. His experiment XLI reads as follows:- "To satisfy ourselves in some measure about the account upon which respiration is so necessary to the animals that nature has furnished with lungs, we took a lark, one of whose wings had been broken by a shot of a man that we had sent to provide us some birds for our experiment; but notwithstanding this hurt, the lark was very lively, and did, being put into the receiver, divers times spring up in it to a good height. The vessel being hastily, but carefully closed, the pump was diligently plied, and the bird for a while appeared lively enough; but upon a greater exsuction of the air, she began manifestly to droop and appear sick, and very soon after was taken with as violent and irregular convulsions, as are wont to be observed, in poultry, when their heads are wrung off; for the bird threw herself over and over two to three times, and died with her breast upward, her head downwards, and her neck awry. And though upon the appearing of these convulsions, we turned the stop-cock, and let in the air upon her, yet it came too late; whereupon casting our eyes upon one of those accurate dials that go with a pendulum, and were of late ingeniously invented by the noble and learned Hugenius, we found that the whole tragedy had been concluded within ten minutes of an hour, part of which time had been employed in cementing the cover to the receiver....... Having proceeded thus far, though there appeared not much cause to doubt, but that the death of the forementioned animals proceeded rather from the want of air, than that the air was overclogged by the steams of their bodies, exquisitely penned up in the glass."

John Mayow, a young chemist, who came under the influence of Boyle, published a "Treatise on Respiration" in 1668. Mayow seems to be the first to recognise that breathing brings the air into contact with the blood. His early death at the age of thirty-four delayed the development of the true conception of respiration by nearly a hundred years.

Gases of respiration

Nearly nine decades later the nature of the gases involved in respiration was brought to light. In 1754 a young Scotsman named Joseph Black, who studied medicine at the University of Edinburgh, showed that the breathing of animals converted common air to "fixed air" which a little later came to be identified as carbon dioxide. His lectures published in 1803 contain the following account:

"I fully intended to make this air, and some other elastic fluids which frequently occur, the subject of serious study. But my attentions then forcibly turned to other objects. A load of new official duties was then laid on me, which divided my attention among a great variety of objects. In the same year, however, in which my first account of these experiments was published, namely 1757, I had discovered that this particular kind of air, attracted by alkaline substances, is deadly to all animals that breathe it by the mouth and nostrils together;...... and I convinced myself that the change produced on wholesome air by breathing it, consisted chiefly, if not solely, in the conversion of part of it into fixed air. For I found, that by blowing through a pipe into lime-water, or a solution of caustic alkali, the lime was precipitated, and the alkali was rendered mild."

While Black was winning renown in Edinburgh, a dissenting clergyman in England by the name of Joseph Priestly was earning his income by acting as librarian for a rich patron, but devoting all his time to chemical experimentation. Priestly discovered a new gas which was given off by growing plants and on which a candle flame fed so readily. His observations (published in 1779) on different kinds of air read: "That plants are capable of perfectly restoring air injured by respiration, may, I think, be inferred with certainty from the perfect restoration, by this means, of air which had passed through my lungs, so that a candle would burn in it again, though it had extinguished flame before, and a part of the same original quantity of air still continued to do so: of this one instance occurred in the year 1771, a sprig of mint having grown in a jar of this kind of air, from the 25th of July to the 17th of August following; and another trial I made, with the same success, the 7th of July 1772, the plant having grown in it from the 29th of June preceding." At about the same time, a Swedish apothecary named Scheele discovered an identical gas ~~and~~ which he termed "fire air".

Respiration as a measure of the food burning in the body

Priestly and Scheele were both in communication with a brilliant French nobleman, Antoine Laurent Lavoisier, a member of the French Academy of Science. At their request, he repeated their experiments and confirmed that "fixed air" was carbon dioxide and gave the name of oxygen to "fire air". He applied the balance and the thermometer to the investigation of the phenomena of life, and concluded that life processes were those of oxidation, with the resulting elimination of heat. - "La vie est une function chemique." His first experiments on the respiration of man were briefly described in a letter to Monsieur Terray, written in Paris and dated November 19, 1790. (Report of the British Association for the Advancement of Science, 1871.) The more important conclusions Lavoisier sums up as follows:-

1. La quantité d'air vital ou gaz oxigène qu'un homme en repos et à jeun consomme, ou plutot convertit en air fixe ou acide carbonique, pendant une heure est de 1200 pouces cubiques de France environ, quand il est placé dans une température de 26 degrés.
2. Cette quantité s'élève a 1400 pouces, dans les mêmes circonstances, si la personne est placée dans une température de 12 degrés seulement.

3. La quantité de gaz oxigène consommée, ou convertie en acide carbonique, augmente pendant le tems de la digestion et s'élève à 1800 ou 1900 pouces.
4. Par le mouvement et l'exercice on la porte jusqu'à 4000 pouces par heure et même davantage.
5. La chaleur animale est constamment la même, dans tous ces cas."

Because of his grasp of the significance of the respiratory process in relation to food, work and temperature, Lavoisier is properly acclaimed as the Father of the Science of Nutrition.

Heat exchanges

About 1842, James P. Joule supplied the chief experimental data which established the mechanical equivalent of heat. In 1845 J. R. Mayer laid down the Law of the Conservation of Energy, and in 1847 Helmholtz independently made the same discovery. Both contributions were rejected by the leading German scientific journal of the day. In 1849 Regnault, professor of physics at the University of Paris, with his assistant, Reiset, working on animals showed that the eating of different kinds of foods made a difference in the oxygen used and the amount of carbon dioxide excreted.

The nature of body fuel

Justus von Liebig, a chemist, was the father of modern methods of organic analysis. In 1851 he showed that the substances oxidised in the body were organic compounds of three types, protein, fat and carbohydrate.

Regularity of heat production

Bidder and Schmidt, two Germans working at the University of Dorpat (1852), concluded that for every species of animal there was a typical minimum of necessary metabolism which was apparent in experiments when no food was taken. Thus:-

"Die Respirationsgrösse, wie jedes andere constituirende Element des Stoffwechsels ist als Function einer Variablen, der jedesmaligen Nährungsaufnahme, plus einer Constanten, der der Thiergattung nach Alter und Geschlecht eigenthümlichen typischen Respirationsgrösse, anzusehen. Diese charakterisirt das Thier einer bestimmten Familie und Gattung, bestimmten Korpervolums, Alters und Geschlechts; sie ist für dasselbe so constant und bezeichnend, wie der anatomische Bau und die demselben entsprechenden mechanischen Verrichtungen seiner Organe."

The first respiration chamber

In 1860 Karl Voit, Professor of Physiology at the University of Munich, and Max von Pettenkofer, Head of the Hygienic Laboratory at the City of Munich, devised a respiration apparatus which could accommodate a large dog. Pettenkofer aspired to work with men, and in 1862 constructed a larger air tight chamber in which a man could stay in comfort for many hours. The cost of the apparatus which was considerable was defrayed by King Maximilian II of Bavaria. Rubner, while working in Voit's laboratory, made a series of valuable calorimetric determinations. He showed that the energy values to the body of starch and fat were equal to the heat produced by burning them in a calorimeter, but that the energy value of protein was different, since it could not be completely burned in the body as it could in the calorimeter. He laid down the isodynamic law, which showed that foodstuffs may, under given conditions, replace each other in accordance with their heat producing value.

Demonstration of the Law of Conservation of Energy in Animals

Rubner became Professor of Physiology at Marburg, and in 1892 evolved an animal calorimeter large enough for a dog and which very accurately measured the heat production of the animal. This he connected with a Pettenkofer-Voit respiration apparatus, and he showed that the heat measured by the calorimeter exactly corresponded to the heat calculated from the oxygen intake and carbon dioxide output and losses of energy bearing material in urine and faeces. An epitome of Rubner's experiments (1894) is here presented.

Table 1.

Comparison of Estimated Heat from Metabolism with Heat actually produced.

Food	No. of days	Heat calculated from metabolism	Heat determined directly	Differences in percentage
Starvation	5	1296.3	1305.2	- 1.42
	2	1091.2	1056.6	
Fat	5	1510.1	1498.3	- 0.97
Meat and fat	8	2492.4	2488.0	- 0.42
	12	3985.4	3958.4	
Meat	6	2249.8	2276.9	+ 0.43
	7	4780.8	4769.3	

By this Rubner confirmed by animal experimentation the fundamental law that energy is neither created nor destroyed in the animal body. Thus the knowledge transmitted personally from the master to the pupil to be in turn elaborated, had its seed in the intellect of Lavoisier.

The respiration calorimeter in America

While Rubner was engaged in these researches in Germany, Atwater, also at one time a pupil of Voit and later Professor of Chemistry at Wesleyan University, Connecticut, worked upon a respiration calorimeter, which was brought to perfection in association with the expert physicist, Rosa (1899). The apparatus was an ingenious engineering feat. As a respiration apparatus it was similar in principle to that of Pettenkofer, and measured only the carbon dioxide excretion. As an instrument for measuring heat it was a constant temperature calorimeter. The space for the subject was large enough for one to live in comfort for several days. The method of computation was based on that of Voit and Rubner. With this apparatus Atwater was able to demonstrate the Law of Conservation of Energy in human beings. An example of his methods is shown in the work of Atwater and Benedict (1899), "Metabolism experiment No. 9, which reads:-

Table 2

Income and Outgo of Energy

Date Jan. 1898	Period	Heat of combustion of food eaten	Heat of combustion of faeces	Heat of combustion of urine	Estimated heat of combustion of protein gained (+) or lost (-)	Estimated heat of combustion of fat gained (+) or lost (-)	Estimated energy of material oxidized in the body a − (b + c + d + e)	Heat determined	Heat determined greater (+) or less (-) than estimated	Heat determined greater (+) or less than estimated
		cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	per cent
10 - 11	7 a.m. to 7 a.m.	2717	142	152	-29	+ 140	2312	2346	+34	+1.5
11 - 12	do	2717	142	160	-36	+ 208	2243	2262	+19	+ .8
12 - 13	do	2717	142	143	-14	+ 200	2246	2302	+56	+2.5
13 - 14	do	2717	142	139	- 4	+ 135	2305	2326	+21	+ .9
Total 4 days		10,868	568	594	-83	+ 683	9106	9236	+130	+1.4
Average 1 day		2,717	142	149	-21	+ 171	2277	2309	+32	+1.4

"The average daily income of energy in this experiment in the estimated heat of combustion of material actually oxidised in the body averaged 2,277 calories per day, and the outgo - in the heat given off from the body and measured - amounted to 2,309 calories. The measured outgo was thus 1.4 per unit larger than the theoretical income." The respiration calorimeter did not include the measurement of the oxygen uptake. Improvements were later instituted by Benedict in 1897, and to-day the Atwater-Rosa-Benedict respiration calorimeter still represents the highest model of technical achievement in this type of apparatus. The automatic feeding of oxygen to the interior of the calorimeter chamber was accomplished by means of a spirometer.

The modern portable respiration apparatus

The conclusive demonstration by means of the respiration calorimeter that energy calculated from the amounts of carbon dioxide excreted and oxygen absorbed by a man lying quietly in the apparatus exactly equals the heat given off by his body in the same period, has made it possible to dispense with the actual measurements of body heat (direct calorimetry) and to rely upon studies of the respiration (indirect calorimetry). Zuntz, Chief of the Agricultural College in Berlin, made a portable respiration apparatus to measure the energy expenditure of a man walking. Subsequently one of his pupils, Magnus-Levy, used this with great success for the study of respiration in disease. This type of apparatus was brought to a much higher state of perfection in 1918 by F. G. Benedict, Director of the Nutrition Laboratory of the Carnegie Institution of Washington. His instrument was easy to operate and inexpensive. The Benedict portable respiration apparatus depends upon the principle that the oxygen breathed in by a subject is used in response to a need of the body and is not stored. Consequently, the oxygen consumed is a measure of the rate of combustion. The ratio of the volume of carbon dioxide expired to the volume of oxygen inspired during the same interval of time was called, by Pfluger, the respiratory quotient. It was shown in 1849 by Regnault and Reiset that the value of the respiratory quotient depended on the nature of food taken. Using this fact and Avagadro's hypothesis, Zuntz and Schumburg have compiled a convenient table for determining the calorie equivalent of each litre of oxygen absorbed. When using the Benedict portable respiration apparatus, the respiratory quotient was assumed as 0.8. The use of this apparatus was known as the closed circuit method of determining energy expenditure as against the open circuit method developed later. In the open circuit method, the use of the Douglas bag (1911) and the Haldane gas analysis (1918) apparatus have proved reliable in many laboratories.

By 1920 methods were available for determining with precision the energy expenditure during various activities. But these methods were time-consuming and ill-adapted to industrial conditions. Thus, the acquisition of data concerning the cost of different types of physical work was difficult. Much of the information came from a study of a few subjects, often the authors themselves, and far more attention was paid to the collection and presentation of data than to their interpretation. The importance of statistical methods of analysis was not generally realised by physiologists until 1925 when Fisher's book, "Statistical Methods for Research Workers",first appeared. Since then, the need of a statistical approach in the interpretation of biological data has been realised and great steps have been made in the development of appropriate techniques. These methods have made possible the rapid assessment of the Calorie needs of large number of persons. The many food shortages caused by the second world war made quick appraisals of the Calorie needs of countries necessary. These statistical methods proved useful here. Such appraisals have been attempted by F.A.O. (1946, 1952) and, as has already been stated, rested in places on very slender physiological foundation. In this thesis a study has been made of variations in the energy expenditure of individuals of different types engaged in various activities.

PART II

INDIVIDUAL VARIATIONS IN THE METABOLIC COST OF STANDARDISED EXERCISES

(The effects of Food, Age, Sex, Height, Weight and Race)

INTRODUCTION

The study of the individual variations in the metabolic cost of human activities is divided into two. ~~parts~~. In this part measurements during standardised exercises in the laboratory are discussed. In the next part measurements of various unstandardised activities in an industrial population /are discussed. The two standard exercises were as follows: the first was a stepping test in which there was measurable external work performed in raising the body weight, and the second was walking, an ordinary everyday activity. In these two activities the movements involved are those to which the subjects are of necessity accustomed in every day life, and so should be little affected by training or practice. In the present investigation, the energy expenditure of 50 persons of varying size and age, male and female, European and Asiatic was studied during the carrying out of two different standard muscular activities.

A statistical analysis of the data shows that energy expenditure during stepping or walking can be very closely predicted from a knowledge of body weight, and that no significant increase in precision is gained by also taking into account height, age, sex, race or resting metabolism. In the case of stepping, energy expenditure may be taken as directly proportional to body weight. In walking, the regression line is also linear but does not pass through the origin.

METHODS

Energy utilisation was determined by indirect calorimetry. Basal metabolic rates and rates lying at rest were measured either with a Benedict-Roth spirometer, assuming an R.Q. of 0.8, or with a Douglas bag. All other rates were obtained using the Kofranyi-Michaelis (K.M.) respirometer (1940). They have devised a portable apparatus for measuring respiratory exchanges. Their instrument is small and light and consists of a dry gas meter which automatically measures and, at the same time, collects aliquot samples of the air passing through the meter. This sample is subsequently analysed in the usual manner with the Haldane gas analysis apparatus, (Douglas and Priestly 1948). This instrument is an important technical advance and with it, it is possible to measure oxygen utilisation over a wide range of activities. With it, Droese, Kofranyi, Kraut and Wilderman (1949) assessed the metabolic cost of the German housewife's manifold activities, and again in a big industrial survey by Lehmann, Muller and Spitzer (1950), it has proved its usefulness. Orsini and Passmore (1951) have compared the results of the cost of a range of simple standardised work, using both the Douglas bag and the K.M. respirometer, and found good agreement between the two. In this investigation the K.M. respirometer used was frequently checked against the Douglas bag method. Gas analyses were carried out in duplicate using the Haldane gas analysis apparatus. The accuracy was checked by analysis of outdoor air at frequent intervals. All estimates covered periods of at least 6 minutes and at most 15 minutes, the average being 10 minutes.

The subjects were chosen from a variety of walks of life: most were either laboratory technicians or post-graduate students,but a few were still at school and some inmates of a home for old people. After an explanation of the nature of the tests, they rested for 30 minutes and then a recording of respiration was made on a Benedict-Roth drum, whilst the subject was recumbent. If a regular respiratory rhythm was shown in the tracing and the subject was breathing smoothly, the tests were made immediately. Some ten volunteers were clearly restless and unable to breathe easily through the mouthpiece. These were rejected: a further four showed irregularities in the tracing and in these the tests were repeated on a second day. The remaining 46 appeared quite at ease with the apparatus and these carried out the exercise tests only once. Five subjects were accustomed to metabolic work but showed no marked difference from the remainder. Although it is well known that training ~~plays~~ produces a marked effect on the cost of such complicated activities as stationary bicycling, Erickson, Simonson, Taylor, Alexander and Keys (1945) have shown that in walking on a treadmill under standardised conditions repetition produces no reduction in metabolic cost. In these simple tests, with ourselves as subjects, we have found no improvement following training. The effects of training are further discussed in the next section (vide p.38).

Stepping was carried out to a metronome at a rate of 15 steps up and down per minute for 10 minutes on to a 10-inch (25.4 c.m.) stool. This is well within the range of optimum efficiency for stepping (Passmore and Thomson, 1950). Walking took place on an indoor track; the subjects walked for 10 minutes at a uniform speed of 3 miles per hour (4.8 milometres per mile). The room temperatures during the experiments ranged from 61-70°F.

EFFECTS OF FOOD

Orr and Kinloch (1921) have carried out a series of experiments on one subject on the effects of food on the metabolic cost of walking. The expenditure of energy per unit of work performed was influenced by the nature of the preceding meal. Following a high protein diet the increase due to work was greater than in the preceding post-absorptive state; after a high carbohydrate diet the increase due to work was less than in the preceding post-absorptive state; and after a high fat meal there appears to be a summation of that extra energy expenditure due to food and of that due to work. Their experiments have been repeated on similar lines and results of experiments where a mixed diet was used is also included.

A summary of the findings and those of Orr and Kinloch are given in Tables 3 and 4. Though in general the findings confirm theirs, it will be seen that the specific dynamic action only amounts to, at most, 2 extra calories per ten minutes. As the standard deviation of the metabolic cost of these standard exercises is of this order, a long series of experiments would be needed to measure the statistical significances of these increases. Table 4 shows that the coefficient of variation during exercise is less than the coefficient of variation under basal conditions. As the effects of food are so slight, relative to the cost of walking and stepping, it was thought unnecessary to carry out our experiments in the post-absorptive state. Instead, the subjects reported either in the forenoon or afternoon, half an hour after a light meal. They then rested, recumbent for 30 minutes before the commencement of observations.

Table 3.

Effect of a previous meal on the calorie expenditure during lying, stepping and walking

Calories per 10 minutes

Subject: K.M., age 41 years. Weight 66 Kg. Height 165 cm.

Nature of Meal	No. of Observations	Lying	Standard Stepping	Walking (3.0 mph)
Post absorptive	9	9.4	40	41
High carbohydrate	3	9.6	41	41
High fat	3	9.8	40	41
High protein	3	12.2	42	42
Mixed breakfast	2	10.8	42	41

Subject: T.B., age 26 years. Weight 57 Kg. Height 165 cm.
(Orr and Kinloch 1921)

Nature of Meal	No. of Observations	Lying	Walking (3.4 mph)
Post absorptive	18	11.1	48.8
High carbohydrate	8	12.9	49.4
High fat	9	11.9	49.6
High protein	7	13.2	52.7

Table 4.

Daily Variations in Individuals Doing Standard Tasks

Subject	Activity	No. of Observations	Energy Expenditure Calories per 10 minutes		Standard Deviation	Standard Error of Mean	Coeff. of Variation %
			Mean	Range			
K.M.	Basal	10	9.3	7.7 10.7	0.8	0.2	7.8
	Standard stepping without food	9	39.8	34 43	2.0	0.6	4.6
	Standard stepping after food	11	41.2	39 44	2.8	0.8	5.0
	Walking 3.0 mph without food	8	41.0	37 43	2.2	0.7	5.1
	Walking 3.0 mph after food	11	41.1	37 44	3.4	1.0	8.2
T.B.	Basal	9	11.0	10.2 12.1	0.7	0.2	6.5
	Walking 3.4 mph without food	18	48.8	45.8 51.6	2.8	0.6	5.8
	Walking 3.4 mph after food	24	50.5	45.8 54.6	2.2	0.4	4.4

EXPERIMENTAL RESULTS

The Calorie expenditure resting, stepping and walking for periods of 10 minutes together with particulars regarding age, sex, race, height and weight for the 50 subjects are given in Table 5. The weight includes the actual weight of the subject, together with that of his clothes and the weight of the K.M. instrument. The apparatus and clothing amounted on an average to 7 - 8 Kg.

Table 6 gives the regression analysis of the energy expenditure of the 50 subjects for ~~during~~ the standardised exercises.

Table 7 shows the mean total energy expenditure during ~~for~~ the 10 minute periods for the stepping and walking tests for different age groups of males and females, Europeans and Asiatics, both uncorrected for weight and corrected to a standard gross weight (70 Kg.).

The findings of an exhaustive statistical analysis carried out by Dr. B. Woolf, of the Department of Animal Genetics, are summarised in Table 8. Multiple regression equations were calculated in which weight, height, age, sex, race and resting metabolism were simultaneously taken into account. In the case of sex, the "dummy variate" method was used, males being scored one and females zero. For race, a joint regression and analysis of covariance technique was employed. The significance of the constant term in the regression was also assessed by

Table 5. Calorie Expenditure Resting, Stepping and Walking

					Energy expenditure Calories per 10 minutes		
Age	Sex	Race	Total Weight (Kg)	Height (cm)	Resting	Standard Stepping	Walking (3.0 mph)
41	M	Eur.	89	181	11	55	51
41	M	Eur.	84	181	11	51	49
29	M	Eur.	73	171	10	42	41
41	M	As.	67	165	10	41	41
41	M	Eur.	69	181	13	47	42
20	M	Eur.	69	170	11	41	45
20	M	Eur.	90	180	11	59	55
34	M	Eur.	83	182	16	53	52
41	F	Eur.	69	170	11	47	46
22	M	Eur.	84	182	16	51	44
28	M	As.	62	162	12	43	36
39	M	Eur.	95	178	16	64	54
38	M	Eur.	75	172	13	47	41
37	M	As.	70	164	11	42	40
48	M	Eur.	92	181	14	58	53
36	M	As.	85	172	12	56	48
26	M	As.	89	173	12	53	50
45	F	Eur.	79	166	11	48	48
22	F	Eur.	72	165	12	46	39
31	F	Eur.	64	152	12	44	40
28	F	Eur.	65	168	10	42	39
26	M	Eur.	86	187	12	56	46
14	M	Eur.	48	150	11	34	37
13	M	Eur.	56	162	13	41	40
13	M	Eur.	56	157	12	36	40
18	F	Eur.	56	157	12	38	38
21	F	Eur.	56	158	11	38	34
20	F	Eur.	62	155	11	42	36
24	M	Eur.	69	177	14	46	48
20	F	Eur.	66	171	11	47	37
18	M	Eur.	110	188	18	76	65
20	F	Eur.	61	157	11	42	33
15	M	Eur.	68	166	13	46	46
17	F	Eur.	64	159	10	42	46
14	F	Eur.	66	162	12	43	43
57	M	Eur.	65	168	11	43	40
32	M	As.	78	172	12	53	50
64	M	Eur.	95	177	12	67	55
79	M	Eur.	68	170	13	46	46
53	F	Eur.	80	158	9	52	48
62	M	Eur.	76	170	11	55	52
34	F	Eur.	65	161	12	47	44
47	M	Eur.	80	176	10	58	41
26	M	As.	69	156	10	44	48
40	M	Eur.	89	188	12	64	60
73	M	Eur.	58	162	7	43	36
38	M	As.	63	162	14	44	39
22	M	As.	69	171	12	45	39
15	F	Eur.	60	151	10	38	34
26	M	Eur.	80	168	12	56	50

Table 6.

Regression Analysis of Energy Expenditure of 50 Subjects During Standardised Activities

	Stepping	Walking
Mean Calories per 10 min.	48.24	44.50
Standard Deviation	8.52	6.98
Coefficient of Variation	17.7 %	15.7 %

Regression Equations

Stepping $C = 0.66\,W \pm 3.02$

Walking $C = 10.24 + 0.47\,W \pm 3.67$

where C = Gross calorie expenditure in 10 minutes

W = Gross body weight in Kg.

Last term is Standard Error of Estimate.

Table 7.

Energy Expenditure during Standard Stepping and Walking
Effects of Age, Sex and Race

Energy Expenditure Calories/10 mins.

Age	Sex	Race	No. of Observations	Mean Weight	Stepping Uncorrected Mean	Stepping Mean 70 Kg.	Walking Uncorrected Mean	Walking Mean 70 Kg.
13-20	M & F	Eur.	14	66.6	44.6	46.8	42.5	44.6
21-45	M	Eur.	12	81.3	52.7	45.4	48.2	41.5
21-45	M	As.	9	72.3	46.8	45.4	43.4	42.0
21-45	F	Eur.	7	68.3	44.4	45.6	41.4	42.5
46-79	M & F	Eur.	8	76.7	52.8	48.1	46.4	42.3

Table 8.

Tests of Significance for Additional Terms in Regression of Calorie Expenditure on Body Weight

5% point for t^2 = 4.04

Proposed New Independent Variate k	Stepping t^2	Walking t^2
(Diversion of Regression Line from Origin)	0.98	11.29
Height	0.09	0.00
Sex	0.00	1.14
Age	2.4	0.05
Race	1.76	0.60
Resting Metabolism	1.31	0.77

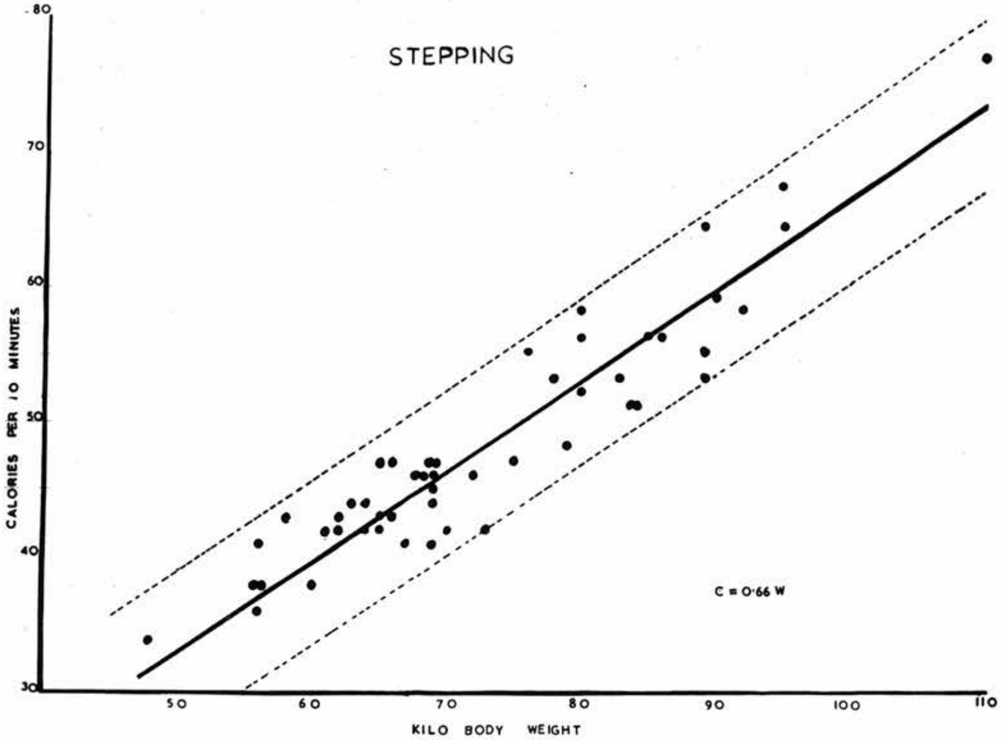
* * * * *

testing whether there was any significant increase in the residual mean square when the line was constrained to pass through the origin.

For stepping, the relation found was very simple. Energy expenditure can be taken as directly proportional to body weight. The mean for all the subjects was 48.2 Calories with a standard deviation of ± 8.52. After taking weight into account, the residual standard error measured round the regression line is reduced to ± 3.02 Calories. This is illustrated in figure 1, which shows the individual values of energy expenditure in relation to body weight, with the regression line drawn in. For walking also, the only variable that need be taken into account is weight. The original standard deviation is ± 6.98 and the standard error of estimate is 3.67. The scatter diagram and regression line for walking are shown in figure 2.

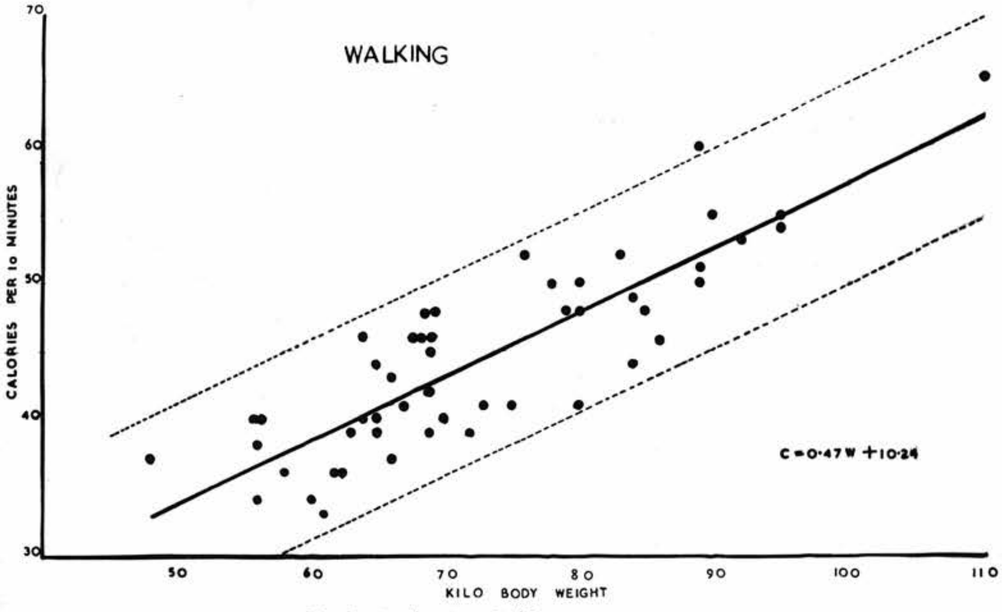
The results indicate that in any physical activity in which a large proportion of energy expenditure is used to move the body weight, the metabolic cost is directly proportional to the body weight. Factors such as age, sex, surface area, race and previous dietary, which are known to play an important part in determining individual basal metabolic rates, do not assume sufficient importance to add to the precision in assessing the cost of such activities. In a large number of

Fig. 1



The dotted lines show twice the SE of Estimate

Fig. 2



The dotted lines show twice the SE. of Estimate.

activities, industrial, domestic and recreational, a major part of the metabolic cost is spent in moving the body. Therefore the fact that weight is the only important individual variable in determining this cost can greatly simplify their assessments.

It may also be concluded that the stepping test seems to have valuable features as a measure of energy expenditure, giving on the average a result exactly proportional to weight and having quite a small residual variance after weight is taken into account.

SUMMARY

The metabolic cost of standardised stepping and walking has been determined in 50 subjects and shown to be proportional to body weight. Statistical analysis showed that no significant increase in the precision of individual assessments is gained by taking into account height, age, sex, race or resting metabolism.

PART III

THE VARIATIONS IN THE METABOLIC COST OF VARIOUS ACTIVITIES OF COAL MINERS AND CLERKS

INTRODUCTION

In Part II the metabolic cost of two standardised exercises have been shown to be proportional to body weight. In standard walking, the metabolic cost was linearly proportional to body weight, and in standard stepping, the metabolic cost was directly proportional to body weight. In view of these findings it is reasonable to assume that in any physical activity in which a large proportion of energy expenditure was used to move the body mass , the metabolic cost is directly proportional to body weight. In Part III a study of the effect of weight on the metabolic cost of various unstandardised activities in an industry has been made. Data were obtained in an investigation into the energy expenditure and food consumption of clerical workers and underground miners at Wellesley Colliery, East Fife, during July - August 1952.

The investigation was undertaken to compare the daily energy expenditure of a group of workers in a heavy industry with that of men whose work was mostly sedentary. It was carried out under the auspices of the Medical Research Council by 38 persons drawn from the Physiology Departments of the Universities of Edinburgh and Glasgow and the Scientific Advisers Division of the Ministry of Food. The writer was a member of this team. His part consisted in helping to organise and carry out in the laboratory the analysis of nearly a thousand samples of expired air and mine air collected by the field workers. He is solely responsible for the statistical analyses of the data presented here.

NATURE OF THE EAST FIFE SURVEY

The introduction of the Kofranyi-Michaelis (K.M.) respirometer by the Max Planck Institute of Arbeitsphysiologie at Dortmund has greatly facilitated studies of energy expenditure by indirect calorimetry. Using these instruments, it has been possible to measure the metabolic cost of a great variety of activities under every day working conditions and in the home, over sampling periods up to as long as 15 minutes. Combining these measurements with records of the time spent in each and every activity (noted minute by minute, if necessary, over the 24 hours), estimations can be made of total daily energy expenditure: this estimate can be divided into amounts utilised at work, during recreation and in bed. Further, such estimations can be compared with the results of dietary surveys. It is thus possible to get two quite independent assessments of dietary requirements for persons of different occupations and to use the two as a mutual check of reliability and accuracy.

In this survey 20 miners and 10 clerks, employed at a colliery in East Fife in Scotland, were studied. For a whole week each man had all the food which he ate weighed and how he spent every minute of his time recorded. The metabolic cost of some 25 samples of his daily life were determined.

SURVEY METHODS

Subjects

I. The Miners

In all, twenty underground workers started: all but one finished seven days on the survey. A domestic crisis, quite unconnected with the work, caused ~~one man~~ him to fall out after four days. Ages varied from 20 to 45 years (see Table 9).

The Nature of the Work

Eighteen of the men were strippers and two brushers. The latter were working on a new development scheme. The strippers were all engaged in producing coal on a long-wall system. The coal had previously been undercut by machinery and the men's work consisted in hewing it with a pick away from the face and loading with a shovel on to mechanically operated pans or conveyor belts. At all the faces wet bulb readings were 70-72°F., except in the one part (the dip mine), where wet bulb readings varied from 81-84°F. Dry bulb readings were usually 2°F. above wet bulb. Temperatures usually rose up to 2°F. during the working of each shift.

Table 9

Age, Height, Weight, Surface Area and B.M.R. of Subjects

Name	Age	Height (ins.)	Weight (net lbs)	Surface Area (sq.m.)	Cal/min. B.M.R. Predicted	Energy Expenditure Asleep Calculated Cal/min.
UNDERGROUND MINERS						
James D.	20	63	120	1.55	0.99	1.07
Willie B.	41	65	121	1.60	0.92	0.75
Benny L.	30	68	121	1.65	1.00	0.87
Tom A.	27	64	126	1.60	0.98	0.84
James C.	41	63	134	1.63	0.94	0.97
Pat C.	32	67	137	1.72	1.04	0.88
Dave S.	30	66	137	1.70	1.01	1.10
George M.	40	65	139	1.69	1.00	1.10
James H.	40	66	140	1.72	1.02	1.02
Willie K.	24	68	142	1.77	1.09	1.14
Jock N.	30	67	145	1.75	1.06	0.93
John H.	32	69	147	1.80	1.09	1.05
James W.	30	68	149	1.80	1.09	-
Alex. W.	33	71	151	1.86	1.12	1.05
George L.	41	63	153	1.73	1.00	0.89
Jock E.	27	70	160	1.90	1.15	1.06
Crawford C.	45	65	164	1.82	1.03	1.19
Will J.	32	65	169	1.84	1.10	1.09
Jock F.	43	65	173	1.85	1.06	1.05
Dave W.	42	71	181	2.02	1.17	1.20
CLERKS						
Jimmie R.	32	67	121	1.63	0.99	0.86
David H.	23	69	132	1.73	1.08	1.12
John A.	22	67	138	1.73	1.09	-
Joe K.	29	67	138	1.73	1.05	1.04
George B.	46	68	142	1.76	1.00	1.10
Willie C.	20	71	144	1.83	1.17	1.12
Ian C.	29	66	145	1.74	1.06	1.13
Bob T.	28	68	149	1.80	1.10	1.05
George C.	32	65	155	1.78	1.07	1.07
James L.	22	70	159	1.83	1.15	1.17

Daily Life

The general daily routine ran thus: All the men were day shift workers. This shift was wound down the pit between 5.45 and 6.0 a.m. and wound up between 1.30 and 2 p.m. After the shift the men returned home and ate a large meal. The majority then slept or dozed for two to three hours in an armchair or on their beds. Then they got up, followed their social and domestic activities and went to bed between 11 p.m. and midnight.

II. The Clerks

Ten acted as subjects. Six worked in check offices recording the attendances of miners and providing the data needed for the making up of their weekly pay packets. Four worked in dispatch offices and were responsible for the weighing of wagons and for their dispatch, labelling and recording. The work was for the most part characteristic of office duties anywhere and involved completion of forms and the keeping of ledgers. Average hours of work were just under 51 hours a week. Most of the men were on a shift system and worked six days a week.

Much of the work was done at high desks at which the clerk could either stand or sit on a high stool. This accounts for the seemingly long time spent in "standing activities". Walking was involved only when going with messages and, in the case of the dispatch clerk when labelling and checking wagons in the railway yards.

One man had a subsidiary weekend job as a barman, one was heavily involved in organising a children's fete, one was a keen bowler and one an all-round athlete. The remainder had no special recreations and spent much of the time at home with their families. Three of these helped their wives ~~materially~~ in the care of young children and the others seemed content for the most part just to "sit and stand".

The Recording of Activities

To determine the calorie expenditure of a miner or clerk, an account of his activities each day, minute by minute, was obtained. These activities were then classified, and the metabolic cost of each was measured. In this way, since the length of time spent in each activity was known and also the calorie cost of each activity, the total calorie expenditure was easily calculated.

At work

During the working shifts an observer was present with each subject and recorded every minute of the working time. For this purpose, a notebook was used, each page of which contained 120 small squares, one square representing one minute. By using a code-letter - e.g. "S" for "sitting", "W" for "walking", "H" for "hewing", etc. - it was possible to record periods of a particular activity to the nearest minute.

Off-duty

For the remainder of the 24 hours every man was asked to register, in a similar notebook, as accurately as possible, how his time was spent. He noted his activities simply. Thus "ST" signified standing in a variety of circumstances. This may have entailed some loss of accuracy in detail, but the resulting simplification probably eliminated larger errors. Every day each subject was visited in his home by an observer, who checked the book and cleared up any obscurities. The times spent on separate activities were added up and the totals transferred to a 24-hour sheet.

The Measurement of the Metabolic Cost of Activities

For this purpose the K.M. respirometer was used. It was worn haversack-fashion on the back (see figures 3 and 4). In this investigation it was used while the subject was doing most strenuous work, and although the conditions were often difficult, none of the men complained of any undue annoyance or inconvenience when wearing it. A light weight perspex valve and sponge-rubber nose clip were used with the machine.

During a period of actual measurement, the quantity of air breathed out and the exact duration of the period were recorded on an analysis sheet (see figure 5), together with a description of the activity. A sample of the expired air was collected in a rubber bladder attached to the machine and from

Fig. 3

Fig. 4

Figure 5.

NAME .... Same Tube No. ....

Date / / Age .... Ht. .... Wt. ....

Time of taking Sample Hrs.

ACTIVITY PLACE

Air Temp .... Barometer ....

Gas Meter	Time sampled m. sec.
Final reading litres	K.M. No. K.M. Factor
Initial " "	Temp. expired air
Difference "	

Observer Leader of Team

Atmospheric corr. factor	Gas Analysis:	Inspired air	Expired air
Ventilation rate 1/m			
	CO_2 %		
	O_2 %		

O_2 consumption 1/m	Calories per min.
R.Q.	

Analyst

Calorie value expired air $\frac{\qquad}{20}$ = O. Calories per min.

the bladder transferred to a glass sampling tube. When underground, a sample of the atmospheric air was also taken approximately simultaneously. This was necessary because of the varying oxygen and carbon dioxide content of the mine air.

The gas sampling tubes were carried in cases specially fitted to hold 10 or 12 tubes, and were filled before use with 0.5% Sulphuric Acid. They were taken daily to the Physiology Laboratory in St. Andrews for analysis of their oxygen and carbon dioxide content, which was carried out by six workers. Gas analyses were done in duplicate. The accuracy was checked by analysis of outdoor air at frequent intervals. In this laboratory also, the sampling tubes were cleaned and refilled with acidulated water, and the accuracy of the K.M. respirometer was periodically checked.

The Collecting of Dietary Data

The estimation of the energy value of the food eaten by each subject during a period of seven consecutive days was made by the individual method by applying conversion factors to the measured weights of food eaten.

Conversion factors from the Medical Research Council's War Memorandum No. 14, "The Nutritive Value of Wartime Foods", together with other analyses prepared in the Scientific Adviser's Division, Ministry of Food, and based on the raw weights used in the making of cooked dishes were used. This investigation was carried out by five dieticians and organised by Miss Grace M. Warnock of the Scientific Advisers Division of the Ministry of Food.

RESULTS

Tables 10 to 14 give all the raw data recorded with the K.M. respirometer. The figures given are the gross observed rates of energy expenditure in Calories per minute. Net values after reduction of basal rates have not been used. Tables 15 and 16 show the estimate of total energy expenditure for typical subjects during one week. In costing activities for which more than one measurement has been made, the arithmetic mean of all the available figures has been used. Table 17 shows the estimated daily average expenditure and estimated daily average intake.

Variations in the metabolic cost of a particular activity may be very great and observational errors may occur. When an unusual figure crops up the question inevitably arises whether or not it is a true reading. Observational errors may occur through gross mistakes in reading the meter or in recording the duration of the sampling: the sample may be diluted with air during transference from the rubber bladder to the sample tube. All the gas analyses were carried out in duplicate and so provide no possibility of gross error. The tables record the results of all observations when the subject appeared to be breathing normally and

Table 10

ENERGY EXPENDITURE AT WORK UNDERGROUND

Miners

Calories per minute

Subject	Sitting	Walking	Loading	Girdering or Timbering	Hewing
James D. 120 lbs.	1.42 1.54 1.62 1.67 2.47 3.40	4.1 5.9 7.3	6.4 7.1 7.4 8.2	5.8	5.8
Willie B. 121 lbs.	1.17 1.34 1.36 1.55	4.8) level 4.9) (6.0 up (6.4	5.5 6.5 6.8 6.8 7.2	4.6 5.1 5.2	6.2 6.3 7.3
Benny L. 121 lbs.	0.96 1.55 1.56	3.8 4.8 5.0 6.0	5.4 5.9 6.9 7.0 7.2 7.7	4.4	5.0
Tom A. 126 lbs.	1.02 1.09 1.14 1.31	3.9 4.0 5.5	(3.4) 5.0 6.1 7.0	4.8	6.4 6.7
James C. 134 lbs.	0.98 1.47 1.66	4.5) level 5.4) 7.7 up	6.0 6.0 6.2 6.5 6.6 6.6	5.0 5.2	5.6 6.1 6.4 6.5 6.8
Pat C. 137 lbs.	1.29 1.50 1.63	7.4 7.5 8.1	5.3 6.3 6.5 7.5	5.2	7.5 7.9 8.2
Dave S. 137 lbs.	1.51 1.53	4.2 4.5 4.7 4.9 5.4 5.5 5.7 5.8	6.1 6.1 6.1 6.9 6.9 7.1 7.3 9.1	5.2 5.2 5.3 5.7	6.3
George M. 139 lbs.	1.50 1.74 2.00	3.7) down 3.7) 7.5 up	7.1 7.5 8.2 8.4	6.4 6.9	7.5
James H. 140 lbs.	0.91 1.20 1.25 1.52 1.63 1.87	5.0 5.3 6.3	5.2 5.8 6.7 6.9	4.1	5.5 6.3

Table 10 contd.

Subject	Sitting	Walking	Loading	Girdering or Timbering	Hewing
Willie K. 142 lbs.	1.73 2.08 2.19	(9.3)	6.1 7.8 10.0	4.9	(10.3)
Jock N. 145 lbs.	1.15 1.71 2.72	5.8 6.2 6.8	5.7 5.7 6.5 9.1	5.8 6.9	6.7
John H. 147 lbs.	1.59 1.59 1.86	5.3 5.3 6.1 7.4 9.4	5.5 5.8 5.9 6.5 6.7 6.9 7.2	6.0 5.4	6.1 7.4
James W. 149 lbs.	1.33 1.42 1.61	5.0 5.8 5.9 8.0	(3.4) (3.7) 8.3	7.2	6.1
Alex. W. 151 lbs.	1.92 2.13	4.1) 4.4) down 4.5) 10.2 up	8.2 8.7 8.9 10.1		8.9
George L. 153 lbs.	1.47 2.08	5.4 down 7.1 up	6.8 8.0		10.5
Jock E. 160 lbs.	1.86 2.35 2.70	(4.6)	7.2 8.5	6.2 6.8	5.7 8.6
Crawford C.	1.45 1.59 1.65	5.7 5.9 6.5	6.2 7.2 8.5 8.9	4.6 7.2	7.0 7.5
Will J. 169 lbs.	1.41 1.52 1.72	5.6)down 5.6) (8.2 (9.1 up (9.7	6.0 6.7 6.8 7.9	5.1	
Jock F. 173 lbs.	1.30 1.36 1.37 1.49 1.73	7.4 8.7 9.7	5.2 5.6 6.6 7.5	5.5	6.6
Dave W. 181 lbs.	1.21 1.32 1.54 1.60	3.6) down 5.1) 10.8 up	6.3 6.7 6.9 7.5	9.0	8.0 8.8 9.4

Additional figures:-

Standing activities	Will J.	2.8 and 4.7 cal/min.
Pulling girders	Will J.	4.6, Dave W. 8.3 cal/min.
Removing steels	Dave W.	4.5 cal/min.
Pushing trucks	Jock F.	4.5 "

Table 11

ENERGY EXPENDITURE DURING RECREATION

Miners

Calories per minute

Subject	Lying	Sitting Activities	Standing Activities	Walking (Own pace)
James D.	1.40	1.42	1.61	3.7
120 lbs.	1.49	1.49	1.68	4.5
	1.50	1.62		5.0
	1.57	1.68		
		1.69		
Willie B.	0.98	1.07	1.29	3.6
121 lbs.	1.09	1.25	1.30	4.0
		1.35	1.37	4.0
		1.51	1.62	
		1.56		
Benny L.	1.07	1.39	1.31	4.5
121 lbs.	1.22	1.44	1.65	4.7
	1.33	1.50		
		1.54		
Tom A.	1.11	1.15		6.3
126 lbs.	1.23	1.32		
		1.33		
		1.43		
		1.52		
James C.	1.29	1.54	1.55	3.8
134 lbs.	1.37	1.58	1.68	4.1
	1.42	1.70	1.95	4.2
		1.80	1.99	
Pat C.	1.01	1.61	1.85	5.8
137 lbs.	1.18	1.70	1.92	6.1
	1.46			
Dave S.	1.21	1.70	2.05	5.0
137 lbs.	1.53	1.79	2.14	5.6
	1.56	1.84		
	1.60	1.86		
	1.78			
George M.	1.32	1.34		4.1
139 lbs.	1.74	1.36		
		1.58		
		1.90		
James H.	1.09	1.26	1.51	4.6
140 lbs.	1.27	1.37	1.65	
	1.66	1.63	1.65	
	1.66			
Willie K.	1.26	1.35	1.84	4.8
142 lbs.	1.63	1.67	1.90	5.3
	1.64	1.71		
	1.83			
Jock N.	1.06	1.36	1.82	6.0
145 lbs.	1.27	1.58		6.9
	1.54			
John H.	0.95	1.38	1.78	4.8
147 lbs.	1.61	1.60	1.85	4.9
	1.61	1.67		
	1.66	1.71		

Table 11 contd.

Subject	Lying	Sitting Activities	Standing Activities	Walking (Own pace)
James W. 149 lbs.		1.30 1.59	1.84	5.3
Alex. W. 151 lbs.	1.42 1.47 1.49	1.46 1.54 1.76 1.87	1.76 1.94 2.40	5.4 6.2
George L. 153 lbs.	1.24	1.35 1.35 1.37		4.7
Jock E. 160 lbs.	0.94 1.43 1.54 1.64 1.83	1.42 1.91 2.00 2.03	1.94 2.16 2.30 2.54	6.6 6.8
Crawford C. 164 lbs.	1.53 1.78	1.60 1.81 1.83 2.10	2.13 2.41	6.4
Willie J. 169 lbs.	1.34 1.45 1.78	1.32 1.42 1.66 1.83 1.96 2.02	1.89 2.13	3.9 4.7
Jock F. 173 lbs.	1.41 1.52	1.55 1.58 1.65	1.92 2.10 2.24 2.35	5.4 7.5
Dave W. 181 lbs.	0.97 1.59 1.66 1.78 1.94 2.05	1.65 1.76 1.79 1.92 2.00	1.56 1.85 1.99	5.7

Table 12

ENERGY EXPENDITURE AT WORK

Clerks

Calories per minute

Subject	Sitting Activities		Standing Activities	
Jimmie R.	1.46		1.51	writing
121 lbs.	1.77	writing	1.96	
	1.79		2.05	
	1.75			
	1.67	writing		
David H.	1.40	writing	1.24	
132 lbs.	1.32		1.35	calculating
	1.22	calculating	1.61	
	1.16	writing	2.20	issuing checks
John A.			1.59	writing
138 lbs.			1.75	"
			(1.22)	calculating
			1.59	writing
			1.89	"
			1.53	"
			2.00	"
Joe K.	1.79		1.81	including weighing
138 lbs.	1.53		1.43	
	1.73		1.34	weighing wagons
			2.01	" "
			1.71	" "
			1.51	writing
George B.	1.38	writing	1.50	weighing wagons
142 lbs.	1.43	"	2.03	" "
	1.38	"	1.71	" "
			1.53	" "
Willie C.	1.64	writing	2.48	
144 lbs.	1.41	"	(1.25)	
	1.69	"	2.44	entering ledgers
	1.65	"	2.47	" "
			2.60	issuing checks
			2.22	
			2.31	checking ledgers
Ian C.	1.72	entering ledgers	1.88	entering ledgers
145 lbs.	1.73	" "	2.15	issuing checks
	1.48	" "	1.67	
Bob T.	1.63	stamping tickets	1.41	weighing wagons
149 lbs.	1.40	writing	1.45	" "
	1.74	folding forms	1.82	" "
	1.56		1.89	" "
	1.43			
	1.42	writing		
George C.	1.75	entering ledgers	2.71	entering ledgers
155 lbs.	1.73	" "	2.10	writing
	1.67	" "	2.10	
	1.75	writing	2.66	entering ledgers
James L.	1.62		2.20	
159 lbs.	1.91	writing	2.23	
	1.93	"	1.85	writing
	1.70			

In addition, whilst walking round a railway siding labelling wagons, George B expended 4.0, 5.3, 5.1 and 3.5 and Bob T. 5.1 and 3.9 cal. per min.

Table 13

ENERGY EXPENDITURE DURING RECREATION

Clerks

Calories per minute

Subject	Lying	Sitting Activities	Standing Activities
Jimmie R.	1.09	1.33	1.43
121 lbs.	1.02	1.09	1.66
	1.02	1.17	1.27
		1.30	
		1.32	
David H.	1.45	1.45	1.42
132 lbs.	1.37	1.21	
	1.10		
	1.49		
John A.		1.68	1.65
138 lbs.		1.53	1.36
		1.54	1.74
		1.40	
		1.63	
Joe K.	1.22	1.65	1.43
138 lbs.	1.20	1.35	
	1.38	1.21	
George B.	1.02	1.12	
142 lbs.	1.04	(0.94)	
	1.34	1.31	
	1.43	1.41	
Willie C.	1.36	1.92	2.09
144 lbs.		1.50	1.50
		1.60	1.33
		1.46	
		1.56	
		1.35	
Ian C.	1.37	1.48	1.56
145 lbs.			
Bob T.	1.22	1.39	
149 lbs.	0.99	1.60	
	1.60		
	1.29		
George C.	1.28	1.53	1.87
155 lbs.	1.32	1.67	1.65
		1.61	1.78
		1.62	
		1.50	
James L.	1.48	1.54	1.82
159 lbs.	1.53	1.55	1.69
	1.28	1.52	1.46
		1.51	2.32

Table 14

ENERGY EXPENDITURE DURING MISCELLANEOUS RECREATIONAL AND OFF WORK ACTIVITIES

Miners and Clerks

Calories per minute

DOMESTIC ACTIVITIES

Washing up	2.9 (Ian C.)	2.6 (David H.)	
Cleaning shoes	2.6 (Geo. B.)	2.8 (Ian C.)	4.0 (Bob T.)
Sweeping floor	3.9 (Bob T.)	Polishing floor	5.1 (Tom A.)
Cleaning windows	4.0 (Geo. B.)	Getting in coals	3.5 (Bob T.)
Breaking sticks	4.9 (Bob T.)	Mending cycle	3.5 (Bob T.)
Playing accordion	2.2 (James W.)	Cobbling	2.7 (Geo. M.)
Washing-dressing	2.6 (Bob T.)		

Playing with Children

Geo. L.	2.3	Ian C.	3.2
John L.	3.3 and 4.6	Jock N.	5.2

Gardening

Geo. M.	8.6	Ian C.	4.8
Geo. B.	5.8	Willie B.	4.4

Cycling (Own pace)

Tom A.	5.9	John H.	6.6	Crawford C.	7.5
Bob T.	10.3	James L.	11.3 and 12.1		

Games

Golf (Joe K.)	5.6 and 4.3
Bowls (Geo. C.)	4.6 and 4.2
Football (James L.)	9.5 (kicking a ball about) and 12.7 (in goal during a practice)

Table 15

Energy Output and Intake of a Coal Miner over One Week

Name: John H.

Age: 32 Height: 69 ins. Weight: 147 lbs.

Occupation: Stripper

	ACTIVITY	Time Spent Hr.	Time Spent Min.	Cal/min.	Total Calories
A	In Bed	58	30	0.94	3690
B	Recreational and off work:-				
	Light sedentary activities	38	37	1.59	3680
	Washing, shaving, dressing	5	3	3.3	1000
	Walking	15	-	4.9	4410
	Standing	2	16	1.8	250
	Cycling	2	25	6.6	960
	Gardening	2	-	5.0	600
	Total recreational and off work	65	21		10,900
C	Working:-				
	Loading	12	6	6.3	4570
	Hewing	1	14	6.7	500
	Timbering	6	51	5.7	2340
	Walking	6	43	6.7	2700
	Standing	2	6	1.8	230
	Sitting	15	9	1.68	1530
	Total working:-	44	9		11,870
	Grant Total	168	-		26,460
	Daily Average	24	-		3,780
	Food Intake Daily Average (determined by diet survey)				3,990

Table 16

Energy Output and Intake of a Clerk over one Week

Name: Ian C.

Age: 29 Height: 66 ins. Weight: 145 lbs.

Occupation: Clerk

	ACTIVITY	Time Spent		Cal/min.	Total Calories
		Hr.	Min.		
A	In bed	54	4	1.13	3670
	Daytime dozing	1	43	1.37	140
B	Recreational and off work:-				
	Light sedentary activities	31	14	1.48	2810
	Washing, shaving, dressing	3	18	3.0	590
	Playing with child	-	30	3.2	100
	Light domestic work	7	14	3.0	1300
	Walking	8	35	6.6	3400
	Gardening	2	48	4.8	810
	Standing activities	6	45	1.56	630
	Watching football	2	10	2.0	260
	Total recreational and off work	62	32		9800
	Working:-				
	Sitting activities	22	22	1.65	2210
	Standing activities	25	57	1.90	2960
	Walking	1	22	6.6	540
	Total Working:-	49	41		5710
	Grant Total	168	-		19,320
	Daily Average	24	-		2760
	Food Intake Daily average (Diet Survey)				2620

and the machine to be in order. A few figures (9 out of 752) appear so far out of line that the probability of observational error must be great. These have been put in brackets and not used in the calculations. All the other figures have been assumed to be a correct record of the cost of the particular activity sampled at that time. This problem appears to be present in all biological observations where exact repetition is impossible. Even with the most careful workers observational errors do occur. Presumably also the statistically unusual sometimes happens.

A full discussion of the data and their implication for the mining industry is not relevant to this thesis, but on the main object of the survey the results are clear cut. Simple additions from the tables show that the average daily distribution of energy expenditure was as follows:-

Average Calorie Expenditure Daily

	In bed and daytime dozing	Recreations and off-work activities	At work	Total
10 Clerks	500	1410	890	2800
19 Miners	490	1420	1750	3660

Thus, there is no evidence that hard work (a daily expenditure of just over 2000 Calories at work over a six day week) in any way reduces the energy expenditure away from work. Here, the writer is concerned with an analysis of the data to show the variability of the metabolic cost of different coal mining activities. The findings are presented under the following headings:-

A. The effect of practice or training in the use of the respiratory apparatus.

B. Variations in the metabolic cost of mining and other activities in relation to body weight.

C. A statistical comparison of the estimated average daily Calorie intakes and expenditures of Clerks and Miners of different weights.

SOME STATISTICAL ASPECTS OF THE RESULTS

A. The Effect of Practice or Training in the use of Respiratory Apparatus

The meaning of the word "training" has altered throughout the centuries. Among those in present use the Oxford English dictionary gives two: "to bring by diet and exercise to the required state of physical efficiency for a race or other athletic feat," and "to instruct and discipline in or for some particular act, profession, occupation or practice". In physiological writing these two meanings have sometimes been confused. In the first sense, all the miners were "trained" and we can add nothing to the physiological understanding of such "training". In the second sense, none of the men were "trained" or, as we would prefer to say, "practiced" in the use of the respiratory apparatus. Although most of the men had seen some type of respiratory apparatus and some had on occasions actually worn them, only one was a trained member of a rescue squad. An analysis of the records of the metabolic cost of activities on successive days, therefore, provides some evidence of the importance of practice in the use of respiratory apparatus. The data recorded in Tables 10 - 13 were obtained irregularly throughout the week. It was unusual to make two observations on the same activity on the same day. For the first observation recorded on each man in each activity, he was comparatively unpractised. At the end of the week all the men were fully accustomed to the apparatus. Therefore a comparison of the first determination of the metabolic cost of any activity with the average cost of all the determinations for that activity for the same man is a fair comparison between relatively "unpractised" and "practised" subjects.

The activities thus analysed are: lying, sitting, standing, loading, girdering and hewing. The data in Tables 10 - 13 were re-arranged for each man according to the order of assessment. ~~and~~ Then a ratio was obtained of the values of the metabolic cost of a given activity determined on the first occasion to the mean of ~~all~~ values of the metabolic cost of all the same activity by the same individual. These values are given for each activity in Tables 18-30.

Table 31 shows the range and mean of these ratios of the different activities for both clerks and miners. Table 32 is a summary of a brief statistical analysis of these figures. It is clear that under our conditions no practice effect was present.

This finding is in contrast to the observations of others who, however, were working in very different circumstances. Thus Robertson and Reid (1952) in their paper on "Standards for the Basal Metabolism of Normal People in Britain" maintain that "training" has an effect on the cost of energy expenditure. They have used the Benedict-Roth spirometer in assessing the measurements and state

CLERKS RECREATIONAL ACTIVITIES

Table 18

Lying

Name	1st Reading	Mean	1st Reading / Mean
Jimmie R	1.09	1.04	1.05
David H	1.49	1.35	1.10
Joe K	1.22	1.27	0.96
George B	1.02	1.21	0.84
Bob T	1.22	1.27	0.96
George C	1.28	1.30	0.98
James L	1.48	1.43	1.04

Range 0.84 - 1.10

Mean 0.99

Table 19

Sitting

Name	1st Reading	Mean	1st Reading / Mean
Jimmie R	1.33	1.24	1.16
David H	1.45	1.33	1.09
John A	1.68	1.55	1.08
Joe K	1.65	1.40	1.18
George B	1.12	1.28	0.88
Willie C	1.92	1.56	1.23
Bob T	1.39	1.49	0.93
George C	1.67	1.59	1.05
James L	1.54	1.53	1.01

Range 0.88 - 1.23

Mean 0.96

Table 20

Standing

Name	1st Reading	Mean	1st Reading / Mean
Jimmie R	1.66	1.45	1.14
John A	1.36	1.58	0.86
Willie C	1.50	1.64	0.91
George C	1.87	1.77	1.05
James L	1.69	1.82	0.92

Range 0.86 - 1.14

Mean 0.97

CLERKS AT WORK

Table 21

Sitting

Name	1st Reading	Mean	$\frac{\text{1st Reading}}{\text{Mean}}$
Jimmie R	1.77	1.69	1.04
David H	1.40	1.27	1.11
Joe K	1.79	1.68	1.06
George B	1.38	1.39	0.99
Willie C	1.64	1.59	1.03
Ian C	1.48	1.64	0.90
Bob T	1.40	1.53	0.91
George L	1.73	1.72	1.00
James L	1.62	1.79	0.90

Range 0.90 - 1.11

Mean 0.99

Table 22

Standing

Name	1st Reading	Mean	$\frac{\text{1st Reading}}{\text{Mean}}$
Jimmie R	1.51	1.84	0.82
David H	1.24	1.40	0.89
John A	1.59	1.72	0.92
Joe K	1.81	1.63	1.11
George B	1.50	1.71	0.88
Willie C	2.48	2.42	1.03
Ian C	1.88	1.90	0.99
Bob T	1.41	1.64	0.86
George C	2.71	2.39	1.13
James L	2.20	2.09	1.05

Range 0.82 - 1.13

Mean 0.97

MINERS' RECREATIONAL ACTIVITIES

Table 23

Lying

Name	1st Reading	Mean	1st Reading / Mean
James D	1.49	1.49	1.00
Benny L	1.33	1.21	1.09
James C	1.37	1.36	1.00
Pat C	1.18	1.22	0.96
Dave S	1.78	1.54	1.15
James H	1.09	1.42	0.76
Willie K	1.26	1.59	0.79
Jock N	1.27	1.29	0.98
Alex W	1.49	1.46	1.02
Jock E	1.43	1.48	0.96
Willie J	1.78	1.52	1.17
Dave W	1.94	1.67	1.16

Range 0.76 - 1.17

Mean 1.00

Table 24

Sitting activities at home

Name	1st Reading	Mean	1st Reading / Mean
James D	1.49	1.58	0.94
Willie B	1.24	1.35	0.91
Benny L	1.39	1.47	0.94
Tom A	1.52	1.35	1.12
James C	1.70	1.66	1.02
Dave S	1.86	1.80	1.03
George M	1.36	1.55	0.87
James H	1.37	1.42	0.96
Willie K	1.35	1.61	0.83
John H	1.38	1.59	0.94
Alex W	1.54	1.66	0.92
George L	1.37	1.36	1.00
Jock E	1.42	1.84	0.77
Crawford C	2.10	1.84	1.14
Willie J	1.96	1.70	1.15
Dave W	1.76	1.82	0.96

Range 0.77 - 1.15

Mean 0.96

Table 25

Standing

Name	1st Reading	Mean	1st Reading / Mean
Willie B	1.62	1.40	1.15
James C	1.55	1.79	0.86
James H	1.51	1.60	0.94
Alex W	2.40	2.03	1.18
Jock E	2.54	2.24	1.13
Jock F	1.92	2.15	0.89
Dave W	1.99	1.80	1.10

Range 0.86 - 1.18

Mean 1.04

Table 26

Walking

Name	1st Reading	Mean	$\frac{\text{1st Reading}}{\text{Mean}}$
James D	3.7	4.4	0.84
Willie B	3.6	3.9	0.92
James C	4.1	4.0	1.02

Range 0.84 - 1.02
Mean 0.93

MINERS AT WORK

Table 27

Sitting

Name	1st Reading	Mean	$\frac{\text{1st Reading}}{\text{Mean}}$
James D	1.67	2.02	0.82
Willie B	1.55	1.36	1.13
Benny L	1.56	1.36	1.13
Tom A	1.09	1.14	0.95
James C	1.66	1.37	1.21
Pat C	1.50	1.47	1.02
George M	2.00	1.75	1.14
James H	1.25	1.40	0.89
Willie K	2.08	2.00	1.04
John H	1.59	1.68	0.94
James W	1.42	1.45	0.97
Crawford C	1.59	1.56	1.01
Will J	1.72	1.55	1.10
Jock F	1.37	1.45	0.94
Dave W	1.54	1.42	1.08

Range 0.82 - 1.21

Mean 1.02

Table 28

Loading

Name	1st Reading	Mean	1st Reading / Mean
Willie K	10.0	8.0	1.25
Jock N	6.5	6.8	0.95
John H	6.7	6.4	1.04
Alex W	10.1	9.0	1.12
Crawford C	8.9	7.7	1.15
Will J	6.7	7.0	0.95
Jock F	5.6	6.2	0.90
Dave W	7.5	6.9	1.08
James D	8.2	7.3	1.12
Willie B	6.8	6.6	1.03
Benny L	5.4	6.7	0.80
Tom A	7.0	6.0	1.16
James C	6.5	6.3	1.03
Pat C	5.3	6.4	0.82
Dave S	6.1	7.0	0.87
George M	8.4	7.8	1.07
James H	5.2	6.2	0.83

Range 0.80 - 1.25

Mean 1.01

Table 29

Girdering

Name	1st Reading	Mean	1st Reading / Mean
Willie B	5.1	5.0	1.02
Dave S	5.7	5.4	1.05

Range 1.02 - 1.05

Mean 1.04

Table 30

Hewing

Name	1st Reading	Mean	1st Reading / Mean
James C	6.8	6.3	1.07
Pat C	7.5	7.9	0.94
Dave W	8.8	8.7	1.01

Range 0.94 - 1.07

Mean 1.00

Table 31

Summary of Ratios of First Observations to the Mean of all Observations

Subject - Clerical Workers	Range	Mean of Ratios
(i) Lying	0.84 - 1.10	0.99
(ii) Sitting activities at home	0.88 - 1.23	0.96
(iii) Standing " " "	0.86 - 1.14	0.97
(iv) Sitting " " work	0.90 - 1.11	0.99
(v) Standing " " "	0.82 - 1.13	0.97
Subject - Miners		
(vi) Lying	0.76 - 1.17	1.00
(vii) Sitting activities at home	0.77 - 1.15	0.96
(viii) Standing " " "	0.86 - 1.18	1.04
(ix) Walking " " "	0.84 - 1.02	0.93
(x) Sitting " " work	0.82 - 1.21	1.02
(xi) Loading " " "	0.80 - 1.25	1.01
(xii) Girdering " " "	1.02 - 1.05	1.04
(xiii) Hewing " " "	0.94 - 1.07	1.01
	Mean of means of all ratios	0.99

Table 32

Analysis of the Means of the Ratios

Number of activities	13
Mean of means of all ratios	0.99
Standard Deviation	0.032

On the hypothesis that practice has no effect it is expected that the ratio of first reading to mean of all readings by the same person doing the same activity should be 1.

The standard error of the difference between 1 and 0.99 is 0.008. Difference between unity and 0.99 is 0.01 which, being only 1.2 times standard error of the difference between 1 and 0.99, is not statistically significant.

that the reading falls on subsequent days. The lowest reading observed in the series was taken as an estimate of the true basal level of metabolism.

Vogelius (1945) has shown that graphs of the results of repeated estimations have revealed a clear "training" effect: successive readings fall rapidly at first, but after about the first four estimations the curve of the results flattens out quickly. He has therefore taken the lowest recorded value or the mean of the last two readings made as an estimate of the asymptote or basal metabolic level which the curve is approaching. This method of repeating observations until stability is apparently achieved is in contrast to the usage adopted by Boothby et al (1936). They took as their basal value "the first determination made for the individual unless, at the time of the test and before its calculation, it was noted as unsatisfactory for reasons of restlessness, observable nervous tension or an elevated temperature." They maintained that readings could vary according to the number of readings taken. Thus even if several readings were taken on a subject the first only was used for computing their normal standards. They stated that "if one departs from the practice of using a single determination made under standard conditions, the number of determinations should strictly be identical for each individual." By this they have suggested that the element of "training" was excluded from their normal standards.

These workers have all used the Benedict-Roth spirometer which is a very sensitive instrument and unless the subject is breathing smoothly with a regular respiratory rhythm the tracing will be irregular.

Experience shows that a few persons are unable to accustom themselves to breathing into a mouthpiece and respiratory apparatus, even with repeated trials. We were lucky in this survey to meet no such subject. The great majority of persons give reliable results once they are observed to be breathing easily and quietly into an apparatus.

B. Variations in the Metabolic Cost of Mining and Other Activities in Relation to Body Weight

Data from seven activities of twenty-nine subjects have been statistically analysed. The assessments of the metabolic cost of each activity were obtained by taking the arithmetic mean of all the observations on each man in each activity. These data were initially studied in four groups:-

(a) Energy expenditure per hour of each miner for the various activities during work underground.
(b) Energy expenditure per hour of each miner for the various activities during recreation.
(c) Energy expenditure per hour of each clerk for the various activities during work.
(d) Energy expenditure per hour of each clerk for the various activities during recreation.

As no differences were found between the cost of the same activities in the miners and clerks, the results were pooled and figures for miners and clerks analysed together. Where separate figures were available for an activity at work and during recreation (for example, sitting, standing) both figures have been included in the analysis.

Weights of the Subjects

Table 33 shows the range, mean and standard deviation of the weights of all the miners and clerks observed in each activity. The weights of the men ranged from 54.6 Kg. to 82.3 Kg.

Table 34 shows the range, mean, standard deviation, standard error and the coefficient of variation of the energy expenditure per hour of the observations for the different activities. For lying, sitting, standing and walking the observations were from both miner and clerks. For girdering, hewing and loading the observations were from miners only. In this statistical analysis hourly rates, rather than minute rates, have been used for arithmetical convenience in the placing of decimal points. All figures are gross values with no deductions for resting or basal values.

In a previous paper Mahadeva, Passmore and Woolf (1953) gave a statistical analysis of the relationship between metabolic cost and body weight in two physical activities, standard stepping and walking, in which a large proportion of energy

Table 33

Range, Mean, Standard Deviation of the Weights of Miners and Clerks

Occupation	Activity	Number of Observations	Weight in Kilograms (W)		
			Range	Mean	S.D.
Clerks & Miners	Lying	28	54.6 82.3	65.7	7.3
Clerks & Miners	Sitting	59	54.6 82.3	65.7	7.0
Clerks & Miners	Standing	35	54.6 82.3	65.5	6.8
Clerks & Miners	Walking	29	54.6 82.3	65.6	7.2
Miners	Girdering	18	54.6 82.3	65.8	8.3
Miners	Hewing	18	54.6 82.3	65.6	8.0
Miners	Loading	20	54.6 82.3	66.1	8.0

Table 34

Range, Mean, Standard Deviation, Standard Error and Coefficient of Variation of the Energy Expenditure of Miners and Clerks

Occupation	Activity	No. of Observations	Energy Expenditure in Calories per hour (C)				
			Range	Mean	S.D.	S.E.	C.V.%
Clerks & Miners	Lying	28	62.4 100.2	82.2	9.9	1.9	12.0
Clerks & Miners	Sitting	59	68.4 138.0	94.8	13.2	1.7	13.9
Clerks & Miners	Standing	35	84.0 145.2	108.6	16.2	2.8	14.9
Clerks & Miners	Walking	29	234.0 402.0	315.6	52.8	9.6	16.7
Miners	Girdering	18	246.0 540.0	342.0	69.0	16.3	20.2
Miners	Hewing	18	300.0 630.0	422.4	78.0	18.4	18.5
Miners	Loading	20	360.0 534.0	424.8	47.4	10.6	11.2

expended is used to move the body weight. In many activities, industrial, domestic and recreational a major part of the metabolic cost would appear to be spent in moving the body.

Table 35 shows, for different activities, the coefficients of correlation of weight to energy expenditure and the corresponding levels of significance. The table shows that at the 5 per cent level of significance, the metabolic cost of all activities except loading is linearly proportional to body weight. For in this process much external work is performed with relatively little body movement.

Regression Analyses

Regression equations have been worked out, for all the activities and are shown in Table 36. The regression lines are illustrated in Figure 6. As a comparison the regression lines for standard stepping and standard walking (Mahadeva, Passmore and Woolf 1953) have been included. They showed that in standard stepping the energy expenditure was directly proportional to weight and the regression line passes through the origin. An analysis of the regression coefficients shows a rise with increasing bodily activity. A study of the regression lines demonstrates a number of factors. The slopes of the regression lines for walking are nearly parallel but the level for the field observations is on a slightly higher plane. This was

Table 35

Correlation of weight to energy expenditure for clerks and miners for the different activities

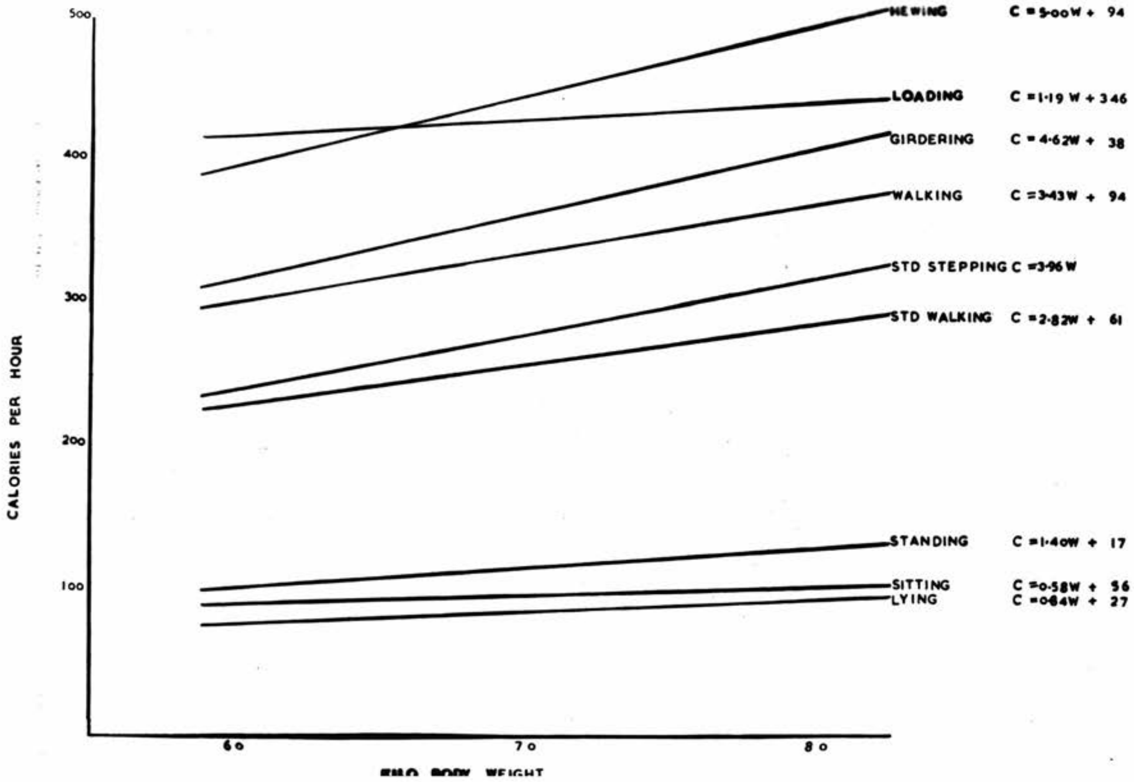
Occupation	Activity	Number of Observations	r	p
Clerks & Miners	Lying	28	0.62	0.001
Clerks & Miners	Sitting	59	0.31	0.02 - 0.01
Clerks & Miners	Standing	35	0.59	0.001
Clerks & Miners	Walking	29	0.46	0.01
Miners	Girdering	18	0.56	0.02 - 0.01
Miners	Hewing	18	0.51	0.03
Miners	Loading	20	0.20	0.4

Table 36

Regression Equations for the Different Activities

Occupation	Activity	Number of Observations	Regression Equation
Clerks & Miners	Lying	28	$C = 0.84\ W + 27$
Clerks & Miners	Sitting	59	$C = 0.58\ W + 56$
Clerks & Miners	Standing	35	$C = 1.40\ W + 17$
Clerks & Miners	Walking	29	$C = 3.43\ W + 94$
Miners	Girdering	18	$C = 4.62\ W + 38$
Miners	Hewing	18	$C = 5.0\ W + 94$
Miners	Loading	20	$C = 1.19\ W + 346$

Fig. 6


500
400
300
200
100
CALORIES PER HOUR
60
70
80
KILO BODY WEIGHT
HEWING C = 5·00W + 94
LOADING C = 1·19 W + 346
GIRDERING C = 4·62W + 38
WALKING C = 3·43W + 94
STD STEPPING C = 3·96 W
STD WALKING C = 2·82W + 61
STANDING C = 1·40W + 17
SITTING C = 0·58W + 56
LYING C = 0·84W + 27

expected as on an average the miners' rate of walking was well above the 3 miles per hour rate studied in the laboratory. The slopes of the regression lines for standard stepping, girdering and hewing are nearly parallel, the level for girdering being higher than that of stepping, and that for hewing higher than the other two. These results are within our expectations. However, as these activities are not of a standardised nature, great care must be taken in drawing further deductions. A striking factor of the distribution of the regression lines is that they are sharply divided into two groups by a relatively wide gap. Those for lying, sitting and standing being below the gap and the other regression lines above. This gap seems to demarcate sharply "light" from "medium" and "heavy" activities and may provide a new angle of approach in assessing industrial work.

C. A Statistical Comparison of the Estimated Average Daily Calorie Intakes and Expenditures of Clerks and Miners of Different Weights

The figures given in Table 17 for average daily expenditure and intake of calories for both clerks and miners have been analysed to determine any relation to individual body weights.

Table 37 shows that there is a relationship between body weights and the corresponding energy expenditure for both clerks and miners which statistically is highly significant. The figures

Table 37.

Correlation of Weight to Calorie Intake and Calorie Expenditure for Miners and Clerks

Occupation		Nos. of Observations	Weight Kg.			Calories per day					r	p
			Range	Mean	S.D.	Range	Mean	S.D.	S.E.	C.V.%		
Clerk	Intake	10	55.0 72.3	64.7	5.0	2500 3830	3044	412	130	13.5	.48	.2 - .1
Clerk	Expend.	10	55.0 72.3	64.7	5.0	2330 3290	2804	353	112	12.6	.85	less than .001
Miner	Intake	19	54.6 82.3	65.9	8.1	3090 5410	4030	557	128	13.8	.35	.1 - .05
Miner	Expend.	19	54.6 82.3	65.9	8.1	2970 4560	3656	459	106	12.6	.72	less than .001

for calorie intake are related with body weight for both clerks and miners but at a very low level of significance.

Table 38 shows a statistical analysis of the average daily calorie intakes and expenditures for both clerks and miners. The calorie intakes are related to the calorie expenditure at a low level of significance. The mean figure for expenditure is about 8 per cent below the mean figure for intake. Considering the difficulties in collecting the basic information and the inherent variability of this biological material, this appears a satisfactory measure of agreement. The following factors may have contributed to the gap.

(a) The more energetic activities may be under-recorded.

(b) When the subjects were wearing the respirometer their activities may have been carried out less energetically than normally.

Neither of these last two errors arose to an appreciable extent during work time, the whole of which was under direct observation. It may be responsible for a low estimate of expenditure during recreation, since only a small proportion of this was directly observed.

(c) The estimate of the energy utilized from the alcohol consumed may have been too high.

(d) The interest in food naturally stimulated by the survey may have caused more food to have been

Table 38

Correlation of Calorie Intake to Calorie Expenditure for Clerks and Miners

		Intake Calories		Expenditure Calories			
	No. of men	Mean	S.D.	Mean	S.D.	r	p
Clerk	10	3044	412	2804	353	.64	.1 - .05
Miner	19	4030	557	3656	459	.40	.1 - .05

consumed than normal. This would, of course, have resulted in a net gain of weight. Unfortunately it was not practicable to weigh the men under comparable conditions at the beginning and the end of the survey.

A point of interest now arises as regards the general value of these findings. In the past the energy requirements for a number of occupations, domestic and industrial and for exercises of various types, have been determined by different workers. Data from two different sources have been used, the first from determinations by indirect calorimetry of the energy expenditure at rest and during different forms of activity, and the second from calculations of the energy value of diets consumed by persons following specific occupations. Each may serve as a check on the other. Towards the close of World War I, when economy of food consumption was a widespread and urgent social necessity, many determinations were made of the energy costs of various kinds of muscular work. Greenwood and Newbold (1922-23) reviewed this subject and analysed the variability of the cost of muscular work carried out in bicycle ergometer experiments reported by Benedict and Cathcart in 1913. They concluded that the variability is such that "it does not appear to be at all probable that the physiological calibration of industrial work can usefully be attempted on a grand scale." Greenwood (1934) subsequently stated that in his opinion indirect calorimetry was a more accurate method of assessment than the dietary method. Orr and Leitch (1937-38) discussing the nature of this variability, state: "the evidence so far as it goes is in favour of the view that calorimetry provides a method which, taken in conjunction with individual time schedules, could be used to give a reliable estimation of the calorie requirements for industrial occupations." Using existing data they have computed the energy requirements of typical occupations by factorial methods. Our own findings of a linear relationship between body weight and energy expenditure in activities involving much movement of the body may add precision to such estimations. The cost of metabolic activities in Orr and Leitch's computations were determined from existing data and have been expressed as for the conventional average man of 1.77 sq. metres body surface.

Our indirect calorimetry and dietary studies seem to present a satisfactory degree of agreement. Each provides a measure of the energy expenditure of the men studied. Whether or not the figures for indirect calorimetry can be integrated with those of other observers to form a "physiological calibration of industrial work on a grand scale", it is perhaps best to reserve judgment.

SUMMARY

1. Data collected during a survey on 20 underground miners and 10 clerks in a colliery in East Fife, Scotland, in August 1952, was submitted to a statistical analysis.

2. For a period of one week the intake of energy and of essential nutrients was gauged for each man by a dietary survey employing the individual weighing method. Simultaneously, over the same period and on the same subjects, the expenditure of energy was determined by means of indirect calorimetry using the Kofranyi-Michaelis respirometer.

3. The average daily Calorie expenditure was found to be as follows:-

	In bed and daytime dozing	Recreation and off-work activities	At Work	Total
10 Clerks	500	1410	890	2800
19 Miners	490	1420	1750	3660

4. The effect of practice or training in the use of the respiratory apparatus was studied in several activities. No significant changes in the metabolic cost of the various activities were found after practice.

5. The seven principle activities studied were lying, sitting, standing, walking, girdering, hewing and loading. The energy expenditure was shown to be linearly proportional to body weight in all the activities except loading, at the 5 per cent level of significance.

Regression equations for body weight and energy expenditure have been worked out for all the activities and shown.

6. A statistical comparison of the estimated average daily Calorie intake and expenditure of the clerks and miners of different sizes show a relationship between body weight and the corresponding energy expenditures for both clerks and miners, which is highly significant ($P < .001$).

The figures for calorie intakes are related to body weight for both clerks and miners but at a low level of significance ($P < .1$ for miners and $P < .2$ for clerks). The factors contributing to this disparity are discussed.

PART IV

THE ENERGY EXPENDITURE AT REST OF SOUTHERN ASIATICS IN BRITAIN

At the end of the last century the German physiologist, Rubner, propounded the law that the heat value of the metabolism of the resting individual is proportional to the area of the surface of the body. This has proved useful for predicting the normal basal metabolic rate (B.M.R.). The three most common methods employed for predicting the normal basal metabolism, that of Aub and Du Bois (1917), that of Harris and Benedict (1919) and that of Dreyer (1920) are based on Rubner's Law. Although all agree upon the character of the fundamental factors that influences metabolism, namely sex, age and body-size, they disagree in their method of treating body size.

The literature on the B.M.R. of various races in different environments is considerable, and there appears to be no unanimity about the range of their variability.

Probably as many investigators claim that race plays no significant role in basal metabolism, as claim that race is a factor. That the problem is complex and the data available to-day are inadequate to solve it, is emphasized by the directly opposite conclusions derived from the same data by two such eminent authorities as Lusk and Du Bois. Lusk (1928) states: "Evidently life at the equator has the same basal metabolism as in temperate climes.

All this is not surprising, for our stock presumably arose in tropical waters many millions of years ago, and we have preserved our heritage. In the future the same level of basal metabolism may be established for men in a laboratory at the North Pole .... on the basis of the whole evidence it does not appear wise to state that the influence of the race or of a tropical climate may greatly reduce the basal metabolism."

Du Bois (1936), when reviewing the studies on racial metabolism, wrote, "In summarizing these results, it seems clear that there are distinct racial differences in metabolism apart from the effects of climate .... no satisfactory explanation has been offered for the racial difference." In 1930, however, Du Bois did not place so much stress upon the racial factor, for he stated: "After all, one gets the impression that the racial differences are so slight that they are almost entirely obscured by the factors of repose, physical training and nutrition." Wilson (1945), in her survey on racial metabolism, states: "So many different factors may play concurrent roles in affecting the basal metabolism, that it is impossible at the present time to say whether the different levels of basal metabolism noted with the various races thus far studied are reflections of a racial characteristic or are the result of a combination of some or all of the factors just mentioned, or even of factors thus far unsuspected." She suggests: "It would be ideal if studies of different races could be made with the same technique by the same investigator or group of investigators, as this would rule out at least the factor of difference in technique........ It would be ideal if many more details could be recorded in future racial studies with regard to the several factors of climate, nature and amount of food intake, physical activity and anthropometric measurement........ In view of the complexity of the problem and the lack of agreement at the present time in the interpretation of the findings in racial studies, it would be desirable to establish a normal standard for each individual race, based on measurements of normal individuals of the race in their native country. When most standards have been established for many different races, a comparison of these with the American and European standards should throw more light on the role played by race in basal metabolism".

Of recent years it has become clear that although in normal man surface area predicts the B.M.R. well, other measurements, which are easier to make and involve no elaborate formulae, predict as accurately or even more so. Brody (1945) and Kleiber (1947) have suggested ~~the~~ a simple power of the weight as giving the best approximation, and the order used is usually between 0.73 and 0.75.

Galvao (1948 and 1950), studying lean, well proportioned and fat men in Brazil, has deduced that the surface law is applicable only in cold climates and not in warm climates. He states that in warm climates the heat production under basal conditions is not proportional to body surface but to metabolic active weight.

Miller and Blyth (1953) measured the basal oxygen consumption, body fat and lean body mass in 48 college students. The body fat content and lean body mass were calculated from body specific gravity determined by the method of underwater weighing described by Behnke. They conclude: "The best metabolic reference standard was found to be the lean body mass (correlation = 0.92). It is pointed out that other standards, such as surface area and body weight may derive much of their variability from their correlation with lean body mass."

Cullumbine (1950), on his work on Ceylonese, has presented results which strongly support Galvao's findings.

Leitch (1951), with a team from the Commonwealth Bureau of Animal Nutrition and Aberdeen University, has made a new international assessment of the normal B.M.R. in relation to sex, stature, age, climate and race by means of multiple regression equations calculated from over 8600 records taken from many parts of the world. The effect of size appears to be more complicated than either surface area or a simple function of the weight. As regards race, she states: "The analysis distinguishes two main groups of people, each with two sub-groups. Subjects from the United States and North Europe form one group. Italians belong to this group in pattern, but have a higher mean level of metabolism. Indians, Chinese and Japanese form the second main group. The Eskimo, American Indian, Polynesian and other races, except possibly Australian aborigines and Somalis, accord in type with the Asiatic group but exceed it in mean metabolism. Data for Australian aborigines and Somalis were so variable that no reliable comparison with other races could be made." These main groups give very different regression equations and accordingly four prediction tables have been drawn up, one for men and one for women in each group.

As there were no British standards for the B.M.R. based on actual measurements in this country, a new set of standards ~~have~~ has been published by Robertson and Reid (1952) after a statistical analysis of the values ~~of~~ from 987 males and 1323 females.

Although the evidence on the whole suggests that there is, in the tropics, a deviation below normal North American standards, the results obtained are by no means consistent. In the literature there are several studies on heat production of Europeans in the tropics, but the literature on Orientals living in temperate climates is surprisingly meagre. There are only two studies on Southern Asiatics living in America and none on those living in Britain. One study was on a group of three South Indian women and the other ~~only~~ only one. An opportunity was taken to do a similar study on Southern Asiatic men living in Edinburgh. Procuring subjects in the post-absorptive state on a cold morning proved difficult. As a result it was decided to study the energy expenditure at rest, about one hour after a normal light meal, as described in Part II of this thesis.

Twenty healthy Southern Asiatic men (Ceylonese, Indians and a Burman), mostly post-graduate medical students, of ages ranging from 20 to 41 years and with ~~of~~ periods of residence in Britain varying from one month to four years, were the subjects. An equal number of healthy Europeans of the same age group were used as control. Their energy expenditure at rest was measured with the Benedict-Roth spirometer. A statistical analysis of the data shows that the energy expenditure at rest of Southern Asiatics and Europeans living in Edinburgh, is not significantly different.

Methods

The subjects rested quietly on a bed for 30 minutes and then a recording of respiration was made on the Benedict-Roth drum, whilst the subject was in the recumbent position. If a regular respiratory rhythm was shown in the tracing and the subject was breathing smoothly, the tests were made immediately.

Four volunteers were restless and unable to breathe easily through the mouthpiece. These were rejected. The remaining 40 were quite at ease with the apparatus and these carried out the test only once. The justification for this is given in Part III of this thesis.

The temperature of the room was maintained between 66° - 72°F.

Results

The energy expenditure at rest per hour per square meter surface area per person one hour after a mixed meal was calculated from each of the tracings. The percentage deviation of this measurement to the corresponding basal rate as predicted in Robertson and Reid's (1952) tables, was next obtained. This served as a convenient method for comparing the Asiatic and European groups and made corrections for age and surface area possible. The resultant values include a measure of the specific dynamic action of the light meal eaten.

Table 39 gives for the Asiatics, their country of origin, period of residence in Britain, age, height, weight, surface area and the energy expenditure at rest per hour per square meter surface area, about one hour after a normal light meal. This table also includes the corresponding predicted basal rates according to Robertson & Reid's and to Leitch's tables and the percentage deviation of the energy expenditure at rest to the corresponding

Table 39

The energy expenditure at rest of Southern Asiatics residing in Edinburgh about an hour after a light meal

No.	Race	Residence in Britain in years	Age in Years	Wt. Kg.	Ht. cms.	Surface Area sq.m.	Cal/hr. resting	Cal/m^2/hr.	Robertson & Reid's prediction for basal	Leitch's prediction for basal	% dev.	
											from R. & R.	from Leitch
1	*C	1	41	62	165	1.68	60.6	36.1	34.5	36.2	+ 4.6	- 0.3
2	C	1/12	26	84	173	1.99	70.2	35.3	37.0	37.3	- 4.6	- 5.4
3	C	2	32	73	172	1.86	73.2	39.4	36.2	36.6	+ 8.8	+ 7.7
4	C	4	26	64	156	1.64	57.6	35.1	37.0	39.1	- 5.1	- 10.2
5	C	½	22	69	171	1.81	70.2	38.8	37.8	37.7	+ 2.6	+ 2.9
6	C	1½	23	71	175	1.86	79.8	42.9	37.6	37.2	+ 12.4	+ 15.3
7	C	½	39	61	163	1.66	78.0	47.0	35.6	36.6	+ 32.0	+ 28.4
8	C	½	31	55	175	1.67	71.4	42.8	36.3	35.8	+ 17.9	+ 19.6
9	C	2	33	67	169	1.77	66.6	37.6	36.1	36.7	+ 4.2	+ 2.5
10	C	½	20	52	169	1.59	71.4	44.9	38.4	37.6	+ 16.9	+ 19.4
11	C	3	30	47	168	1.51	66.6	44.1	36.4	36.8	+ 21.2	+ 19.8
12	C	1	21	67	164	1.73	79.8	46.1	38.1	38.7	+ 21.0	+ 19.1
13	*I	½	28	57	162	1.60	70.2	43.9	36.6	38.0	+ 19.9	+ 15.5
14	I	¾	37	65	164	1.71	67.2	39.3	35.7	36.9	+ 10.1	+ 6.5
15	I	2	36	80	172	1.93	69.0	35.8	35.8	36.5	0	- 1.9
16	I	1½	32	62	159	1.64	58.2	35.5	36.2	37.9	- 1.9	- 6.3
17	I	½	37	53	166	1.58	58.8	37.2	35.7	36.3	+ 4.2	+ 2.5
18	I	½	31	77	173	1.91	58.2	30.5	36.3	36.8	- 16.0	- 17.1
19	I	½	36	74	177	1.91	60.6	31.7	35.8	35.6	- 11.5	- 11.0
20	*B	1	32	67	177	1.83	84.0	45.9	36.2	35.8	+ 26.8	+ 28.2
		Total	613	1307	3370	34.88	1371.6	789.9	729.3	740.1	+ 163.5	+ 135.2
		Average	30.7	65.4	168.5	1.74	68.58	39.50	36.47	37.0	+ 8.2	+ 6.8

C - Ceylonese I - Indian B - Burman

predicted basal rates of these authors. Table 40 gives for Europeans, the age, height, weight, surface area and the energy expenditure at rest per hour per square meter surface area, about one hour after a normal light meal. This table also includes the corresponding predicted basal rates according to Robertson and Reid's tables and to Leitch's tables and the percentage deviation of the energy expenditure at rest to the corresponding predicted basal rates of these authors.

The average percentage deviations above Robertson and Reid's prediction for basal rates for the two groups were 8.2 for the Asiatics and 9.3 for the Europeans. In view of the fact that the nature of the light meal eaten by the subjects prior to the experiment is about the same, these figures are of the order that one would expect and include the specific dynamic action of the food eaten.

Table 41 gives a statistical analysis of the percentage deviation above and below Robertson and Reid's prediction for basal for the Asiatic and European group. The analysis shows that the energy expenditure at rest of Southern Asiatics and Europeans living in Edinburgh is not significantly different.

Table 40

The energy expenditure at rest of Europeans residing in Edinburgh about an hour after a light meal

No.	Age in years	Wt. Kg.	Ht. cms.	Surface Area sq.m.	Cal/hr. resting	Cal/m^2/hr.	Robertson & Reid's prediction for basal	Leitch's prediction for basal	% Dev. from R. & R.	% Dev. from Leitch
1	41	84	181	2.05	68.4	33.4	34.5	35.5	- 3.2	- 5.9
2	29	68	171	1.80	58.8	32.7	36.5	37.3	- 10.4	- 12.3
3	41	64	181	1.82	78.6	43.2	34.5	35.5	+ 25.2	+ 21.7
4	20	64	170	1.74	67.8	39.0	38.4	38.5	+ 1.6	+ 1.3
5	20	85	180	2.06	63.0	30.6	38.4	37.8	- 20.3	- 19.0
6	38	70	172	1.82	75.0	41.2	35.7	36.2	+ 15.4	+ 13.8
7	26	81	187	2.06	73.8	35.8	37.0	36.9	- 3.2	- 2.9
8	24	64	177	1.79	82.8	46.3	37.3	37.7	+ 24.1	+ 22.8
9	26	75	168	1.85	69.0	37.3	37.0	38.0	+ 0.8	- 1.8
10	30	65	171	1.76	64.2	36.5	36.4	37.4	+ 0	- 2.4
11	25	75	163	1.80	84.6	47.0	37.1	38.7	+ 26.7	+ 21.4
12	21	68	180	1.86	66.6	35.8	38.1	37.8	- 6.0	- 5.3
13	21	64	173	1.76	70.2	39.9	38.1	38.4	+ 4.7	+ 3.9
14	23	71	179	1.89	88.2	46.7	37.6	37.6	+ 24.2	+ 24.2
15	21	75	179	1.93	83.4	43.2	38.1	37.9	+ 13.4	+ 14.0
16	39	65	172	1.77	76.8	43.4	35.6	36.2	+ 21.9	+ 19.9
17	39	66	173	1.78	84.6	47.5	35.6	36.4	+ 33.4	+ 30.5
18	35	70	178	1.87	72.6	38.5	35.9	36.3	+ 8.1	+ 6.9
19	23	67	171	1.78	85.2	47.9	37.6	38.2	+ 27.4	+ 25.4
20	38	66	177	1.81	66.6	36.8	35.7	36.2	+ 3.1	+ 1.7
Total	580	1407	3503	3700	1480.2	803.0	735.1	744.5	+ 186.9	+ 157.9
Average	29.0	70.4	175.2	1.85	74.01	40.2	36.76	37.22	+ 9.3	7.9

Table 41

The mean percentage deviation of the energy expenditure at rest to Robertson & Reid's Prediction for basal metabolism is 8.2 for Southern Asiatics

The standard deviation of the percentage deviation for Southern Asiatics is 12.8

The mean percentage deviation of the energy expenditure at rest to Robertson & Reid's prediction for basal metabolism is 9.3 for Europeans

The standard deviation of the percentage deviation for Europeans is 14.8

The standard error of the difference between the two means is 4.3

The difference between the means is 1.1

The energy expenditure at rest of Europeans and Southern Asiatics resident in Edinburgh is not significantly different

* * * * *

Discussion

In the analysis of the data corrections have been made for age and surface area. As both groups were residing in Edinburgh and the laboratory was maintained at a constant temperature, climatic factor is excluded. No correction was made for race. Statistically the two groups were shown to be not significantly different, showing that there is no apparent influence of race on resting metabolism. There is no literature on the energy expenditure at rest of Southern Asiatics resident in temperate zones, one hour after a light meal. As such, the results of this investigation cannot be confirmed. The claim that race is a factor in determining the level of basal metabolism appears to be based on three types of findings: (1) That the basal metabolism values found with different races of people in various parts of the world lie appreciably above or below the average normal standards established for Americans and Europeans; (2) That the metabolic rates of Southern Asiatics are below the normal standards, even when individuals of these races are living in a temperate climate and leading the life of Westerners; and (3) That the basal metabolism of Europeans living in the tropics either shows no deviation from normal standards or only a slight decrease or increase but in any event usually not so great a deviation as noted with active inhabitants of the tropics.

(1) Studies of the B.M.R. of Southern Asiatic men in their countries of origin show a heat production below European standards. Thus in India, Mukherjee (1926), from his observations on 15 Bengalee male medical students between the ages of 22 and 27 years, at Calcutta, found the basal metabolism to be 14 per cent below the Aub and Du Bois standards. Mukherjee and Gupta (1931) investigated the B.M.R. of 18 Bengalee medical students at Calcutta and observed a deviation of 13.3 per cent below the Aub and Du Bois standards. Banerji (1931) found the basal metabolism of 145 prisoners of Lucknow district jail to be 6.9 per cent below European standards. Krishnan and Vareed (1932) also reported values for men considerably lower than the Harris-Benedict and Aub-Du Bois standards. Bose and De (1934) carried out observations on 30 men at Calcutta and their results were within 5 per cent of the standards of Aub and Du Bois. Rahman (1936) conducted experiments on 32 young men in Hyderabad and found a deviation of 8.7 per cent below the Aub-Du Bois standards. Rajagopal (1938) reported values 12.5 per cent below Aub and Du Bois standards on 26 men in Coonoor, and Ahmed et al (1938) 8.9 per cent on subjects in Calcutta. Niyogi, Patwardhan and Mordecai (1939) investigated the B.M.R. of 24 men in Bombay and showed lower readings than the Mayoclinic, Harris-Benedict and Aub-Du Bois standards. Sokhey and Malandkar (1939), working on 60 men in

Bombay, showed that there was a deviation of 8 per cent below the Aub-Du Bois standards. Munro (1950) in his studies on Indians and British residents in India, observed a value of 9.6 per cent below the Aub-Du Bois standard on a group of 40 Indians in Bombay.

The studies of the B.M.R. of Southern Asiatic women in their countries of origin also show a lowered heat production than the European standards. Thus Mason and Benedict (1931) in their studies on Tamil, Malayali and Telugu women in Madras, observed values of 16.8 per cent, 18.2 and 15.8 per cent respectively below the Aub-Du Bois standards. Krishnan and Vareed (1932) on their studies of 15 women in Madras obtained 16.2 per cent below Aub-Du Bois. Niyogi et al (1939) also obtained a value of 13.8 per cent below Aub-Du Bois on 52 women in Bombay.

In Ceylon, the studies by Cullumbine (1950) on fifty healthy male students of ages varying from 21 to 25 years, gave an average basal value of 13.6 per cent lower than that predicted by Robertson and Reid.

The result of the investigation of the B.M.R. of Southern Asiatics in their country of origin is summarised in Table 42. The percentage deviation from the Robertson and Reid, the Aub and Du Bois and the Leitch's standards are given for comparison.

2. Two investigations on Southern Asiatics for B.M.R. have been carried out in America. Mason

Table 42

The results of investigations on basal metabolism by all workers on Southern Asiatics living in Southern Asia

MEN

No.	Author and Year	Place	Sex	No. of Subjects	Av. Age Years	Wt. Kg.	Ht. cms.	Surface Area	Cal/m^2/ hr/	Deviation from			Type of apparatus used
										R. & R.	Aub & Du Bois	Leitch	
1	Mukherjee (1926)	Calcutta	M	15							- 14		
2	Mukherjee & Gupta (1931)	Calcutta	M	18	25	52.4	168	1.59	34.26	- 7.7	- 13.3	- 5.5	D.B. & gas analysis
3	Banerji (1931)	Lucknow	M	100									Benedict
4	Krishnan & Vareed (1932)	Madras	M	54					34.8		- 12.0		B.Roth
5	Bose & De (1934	Calcutta	M	30							±		Sanborn
6	Rahman (1936)	Hyderabad	M	32	22	54.2	169.3	1.62	36.2	- 2.9	- 8.7	- 0.6	Sanborn
7	Rajagopal (1938)	Coonoor	M	26	31	56.0	168.0	1.61	34.4	- 5.2	- 12.5	- 8.6	B. Roth
8	Ahmed et al.(1938)	Calcutta	M	9	27	60.3	166.7	1.67	36.49	- 0.8	- 8.99	- 0.8	D.B. & gas analysis
9	Niyogi et al. (1939)	Bombay	M	24	22.9	52.7	166.1	1.57	34.5	- 8.5	- 12.9	- 7.5	Sanborn
10	Sokhey & Malandkar (1939)	Bombay	M	60	26.2	55.5	167.9	1.62	36.3	- 1.9	- 8.0	- 0.81	Tissot & gas analysis
11	Khanna & Machanda (1946)	Lahore	M	60					35.66				D.B. & gas analysis
12	Munro (1950)	Bombay	M	40	21.6	56.8	170.2	1.65	36.3	- 4.0	- 9.6	- 1.6	B.R.
13	Cullumbine (1950)	Colombo	M	50	23.1	52.1	160.6	1.53	32.4	- 13.6		- 13.6	D.B. & gas analysis

6.9% below Eur. standard

Table 42 contd.

The results of investigations on basal metabolism by all workers on living in Southern Asia

WOMEN

No.	Author and Year	Place	No. of Subjects	Av. Age Years	Wt. Kg.	Ht. cms.	Surface Area	Cal/m^2/ Hr.	Deviation from			Type of apparatus used
									R. & R.	Aub & Du Bois	Leitch	
1	Mason & Benedict (1931)	Madras:-										
		Tamil	27	21	44.9	154	1.39	31.3	- 8.2	- 16.8	- 6.6	Benedict
		Malayali	17	21	45.7	156	1.40	30.9	- 9.4	- 18.2	- 8.0	
		Telugu	6	22	43.5	153		31.3	- 7.9	- 15.8		
2	Krishnan & Vareed (1932)	Madras	15					31.0		- 16.2		B.R.
3	Niyogi et al (1939)	Bombay	52	22	44.9	152.8	1.38	32.05	- 5.7	- 13.8	- 6.3	Sanborn

(1934), working on the B.M.R. of three Indian women measured in two climates, showed an increase in metabolism of 4.8 per cent in cold climates. She suggests that approximately 5 per cent of the low metabolism previously reported for Indian women may be attributed to the effect of tropical climates. Turner and Benedict (1935), investigating the basal metabolism of ten well nourished oriental women (Chinese, Japanese, Korean and one South Indian) who had lived from one to five years in the United States, in an American college environment and partaking of an American college diet, showed that their B.M.R.'s averaged 12 per cent below the prediction standard and was lower than that of six American college mates. Comparison of the urinary nitrogen excretion of five of these orientals and five of their American college mates (each pair living in the same college dormitory and eating off the same table) indicated that the orientals were not subsisting upon an abnormally low protein diet, and they suggest that the low basal metabolism noted with these foreign born Orientals under an American environment, cannot be ascribed to a low protein metabolism.

(3) The basal metabolic studies of Europeans resident in Southern Asiatic countries do not show the same response in all instances. In some there was a decrease, in others there was no change. Thus Mason (1940) showed a deviation of 12.5 per cent

below Aub and Du Bois standards in her studies on 34 European women residing in Madras. Her studies on 9 European women in both temperate and tropical climates showed two types of response to the tropics. One group showed a marked decrease in metabolism and the other group showed no change in metabolism. Rajagopal (1938) studied the B.M.R. of 20 Europeans and 26 Indians in Coonoor at an altitude of 6000 feet above sea level. Most of the Europeans observed were in Coonoor for 5 months and had seen service in India for not less than one year. They showed a deviation of 4.3 per cent below Aub and Du Bois. Similar studies on 26 Indians showed that the metabolism of the Indians who lived for 3 years in the cool, dry climate of the hills in Coonoor was significantly higher than that of some Indians who had lived there for only 2 months.

McGregor and Loh (1941) determined the B.M.R. of two groups of 35 Europeans resident in Singapore for periods of ½ year and 2½ years. The former group showed a value of 4.5 per cent and the latter of 6.1 per cent below Aub and Du Bois. He is of the opinion that the basal metabolism of Europeans shows a definite depression in tropical environment in certain normal individuals. This depression is absent in others. The depression in metabolism in the subjects affected in this way appears to reach a maximum before the end of the first year in the tropics. This lower value is shown to be maintained after 2 years in the tropics. He concludes that climate rather than dietetic or occupational influences is primarily responsible for the variation.

Munro (1950) studied the B.M.R. of 78 British airmen resident in Bombay and compared it with a similar study on an Indian group of 40. The B.M.R. of the Indian group was 9.6 per cent below the Aub and Du Bois standard, whilst that of the British group which had been in the tropics for 10.7 months was 5.6 per cent below the Aub and Du Bois standards. He also showed that the basal metabolism of the British who lived for 3 years in the tropics was close in value to that of the Indian group. Further observations in Kashmir showed that a few days' exposure to a cold hill climate was sufficient to raise the basal metabolism of the group of British subjects significantly above the tropical level.

The results of the investigation of the B.M.R. of Europeans resident in Southern Asiatic countries is summarised in Table 43. The percentage deviations from the Robertson and Reid, the Aub and Du Bois and the Leitch standards is given for comparison.

Investigators working in other parts of the world also have shown the same result. Martin (1930), following the variation of his own B.M.R. during a journey to Australia, observed an abrupt deviation in level, in response to an extreme rise in air temperature.

Increased muscular relaxation in the heat

Table 43

The results of investigations on basal metabolism by all workers on Europeans resident in Southern Asia

MEN

No.	Author	Place	Residence in years	No. of Subjects	Av. Age Years	Wt. Kg.	Ht. cms.	Surface Area	Cal/m^2/hr.	R. & R.	% Deviation			Type of Apparatus used
											R. & R.	Aub & Du Bois	Leitch	
1	Rajagopal (1938)	Coonoor	>1	20	25	62.2	173	1.73	37.8	37.1	+ 1.9	- 4.3	- 1.6	B.R
2	McGregor & Loh (1941)	Singapore	½	35	22	64.2	171.2	1.74	37.88	37.8	+ .2	- 4.5	- 0.3	B.R
			2½	35	23	64.4	172.1	1.75	37.04	37.6	- 1.5	- 6.1	- 2.0	
3	Munro (195)	Bombay & Kashmir	5/6	78	24.7	63.7	174.5	1.76	37.4	37.1	+ .8	- 5.6	0	B.R.
				WOMEN										
1	Mason (1934)	Madras	1/6-31	34	35	54.6	163	1.58	32.0	33.5	- 4.5	- 12.5	- 1.5	

might be suspected in this instance as the cause of the fall.

Rabinowitch and Smith (1936) believe that the high metabolic rate of the Eskimo fits in with the cold environment, which is known to increase metabolism: that constant stimulation of cold weather should theoretically tend toward increased muscle tone: and that the basal metabolism is to a large extent a function of active protoplasmic mass. Crile and Quiring (1939) and Steggarda and Benedict (1932) also have found this higher B.M.R. for Eskimoes.

Reviewing the literature quoted above, it appears to be a formidable task to make any statistical conclusion from the findings, on account of the various erroneous factors that creep in in the determination of the B.M.R. These factors include technique, functional normality, diet, climate, social "milieu", degree of physical activity, muscular relaxation, anthropometric measurement and normal standards.

In the main the present investigation has shown no significant difference between the energy expenditure at rest of Europeans and Southern Asiatics residing in Edinburgh. The number of the Southern Asiatics studied here and the variations of their periods of residence are too small to come to any definite conclusions as regards the nature of the increase in metabolism from that in their own native country. It is not clear, when an increase in B.M.R. occurs due to a change to a cold climate, whether it is characteristically sudden or slow and progressive. Studies of Southern Asiatics in their country of origin have shown a deviation below Western standards. Studies of Europeans residing in Southern Asiatic countries have shown no change, or a decrease from Western standards. From the above findings, it is reasonable to conclude that climate plays some part in influencing resting metabolism.

Summary

1. The energy expenditure at rest of 20 Southern Asiatics living in Edinburgh was determined about one hour after a light meal and compared with that of 20 Europeans of the same age group.

2. A statistical analysis of the findings shows that the energy expenditure at rest of Southern Asiatics and Europeans resident in Edinburgh about one hour after a light meal is not significantly different.

3. The influence of climate on resting metabolism is discussed.

ACKNOWLEDGEMENTS

The author wishes to thank Professor F. A. E. Crew and Professor D. Whitteridge for providing facilities in their Departments for this work. To Dr. R. Passmore he expresses his deep gratitude for expert advice and invaluable guidance throughout these investigations. He is indebted to Dr. B. Woolf for his help with the statistical analysis.

Parts of the costs of the investigation were met from a grant made by the Medical Research Council.

REFERENCES

1. ATWATER, W.O. and BENEDICT, F.G. (1899) Experiments on the Metabolism of matter and energy in the human body. U.S. Dept. of Agriculture office of experiment station Bull. 69.
2. ATWATER, W.O. and ROSA, E.B. (1899) Description of a new respiration calorimeter and experiments on the conservation of energy in the human body. U.S. Dept. of Agriculture Bull. 63.
3. AUB, J.C. and DU BOIS, E.F. (1917) Arch. Intern. Med., 19: 823.
4. BANERJI, N.D. (1931) Basal metabolism of the Prisoners of the District Jail, Lucknow. Ind. J. med. Res., 19: 229.
5. BIDDER and SCHMIDT (1852) Die Verdauun gasafte und der Stoffwechsel, 348.
6. BLACK, J. (1803) Lectures on the elements of chemistry delivered in the University of Edinburgh. Robinson
7. BOOTHBY, W.M., BERKSON, J., DUNN, H.L. (1936) Studies of the energy of metabolism of normal individuals: a standard for basal metabolism, with a normogram for clinical application. Amer. J. Physiol., 116: 468.
8. BOYLE, R. (1772) The works of the Honourable Robert Boyle, Vol. 1, 97. Rivington.
9. BRODY, S. (1945) Bioenergetic and Growth. Reinhold Publ. Corp., New York.
10. CRILE, G.W. and QUIRING, D.P. (1939) J. Nutr., 18: 361.
11. CULLUMBINE, H. (1950) Heat production and energy requirements of tropical people. J. app. Physiol., 2: 640.
12. DOUGLAS, C.G. (1911) J. Physiol., 42: xvii.
13. DOUGLAS, C.G. and PRIESTLY, J.G. (1948) Human Physiology. The Haldane gas analysis apparatus and its use, 1.
14. DREYER, G. (1920) The normal basal metabolism in man. Lancet ii, 289.

References contd.

15. DROESE, W., KOFRANYI, E., KRAUT, H. and WILDEMAN, L. (1949) Arbeitsphysiologie, 14: 63.

16. DU BOIS, E.F. (1936) Basal metabolism in Health and Disease, 200.

17. DU BOIS, E.F. (1930) Recent advances in the study of basal metabolism. J. Nutr. Part I, Vol. 3, 225.

18. ERICKSON, L., SIMONSEN, E., TAYLOR, H.L., ALEXANDER, H. and KEYS, A. (1946) The energy cost of horizontal and grade walking on the motor driven treadmill. Amer. J. Physiol., 145: 391.

19. FISHER, R.A. (1925) Statistical Methods for Research Workers.

20. FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS. Report of the Committee on Calorie Requirements. Washington (1950).

21. FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS. First World Food Survey (1946). Second World Food Survey (1952).

22. GALVAO, P.E. (1948) Human heat production in relation to Body weight and Body surface. I.Inapplicability of the surface law on lean men of the tropical zone. II. Inapplicability of the surface law on well proportioned men of the tropical zone. J. appl. Physiol., 1: 385.

23. GALVAO, P.E. (1950) Human heat production in relation to body weight and body surface. III. Inapplicability of surface law on fat men of the tropical zone. IV. General interpretation of climatic influence on metabolism, 3, 21.

24. GREENWOOD, M. (1934) The statistical aspects of the problem of national nutrition. xxii session. Inst. Internat. Statistique. Londres.

25. GREENWOOD, M., and NEWBOLD, E.M. (1922-23) On the estimation of metabolism from determinations of carbon dioxide production and on the estimation of external work from the respiratory metabolism. J. Hyg. Camb., 21: 440.

26. HALDANE, J.S. (1918) Methods of air analysis.

References contd.

27. HARRIS, J.A. and BENEDICT, F.G. (1919) A Biometric study of basal metabolism in man. Carnegie Institute of Washington Pat. No. 279.

28. HIPPOCRATES (1891) Genuine works of Hippocrates by F. Adams. William Wood, 197.

29. KLEIBER, M. (1947) Body size and metabolic rate. Physiol. Rev., 27: 511.

30. KOFRANYI, E., and MICHAELIS, A.F. (1941) Arbeitsphysiologie, 11, 148.

31. KRISHNAN, B.T. and VAREED, C. (1932) Basal metabolism of young college students, men and women, in Madras. Ind. J. med. Res., 19, 831.

32. LAVOISIER, A.L. (1871) Report of the British Association for the Advancement of Science, Edinburgh. Letter to Monsieur Terray, 189.

33. LEHMANN, G., MULLER, E.A. and SPITZER, H. (1950) Arbeitsphysiologie, 14, 166.
33a. LUSK, G. (1928) The science of nutrition, 166.
34. MacGREGOR, R.G.S. and LOH, G.L. (1941) The influence of a tropical environment upon the basal metabolism, pulse rate and blood pressure in Europeans. J. Physiol., 99: 496.

35. MARTIN, C.J. (1930) Thermal adjustments of man and animals in the tropics. Lancet, 2, 617.

36. MASON, E.D. (1934) The basal metabolism of European women in South India and the effect of change of climate on Europeans and South Indian women. J. Nutr., 8: 695.

37. MASON, E.D. (1940) The effect of change of residence from temperate to tropical climate on the basal metabolism, weight, pulse rate, blood pressure and mouth temperature of 21 English and American women. Amer. J. trop. med., 20: 669.

38. MASON, E.D. and BENEDICT, F.G. (1931) The basal metabolism of South Indian women. Ind. J. med. Res., 19: 75.

39. MILLER, A.T. and BLYTH, C.S. (1953) Lean body mass as a metabolic reference standard. J. appl. Physiol., 5, No. 7, 311.

References contd.

40. MUKHERJEE, H.N. (1926) The basal metabolism of men in the tropics. J. Amer. med. Ass. 86: 1384.

41. MUKHERJEE, H.N. and GUPTA, P.C. (1931) The basal metabolism of Indians. Ind. J. med. Res., 18: 807.

42. MUNRO, A.F. (1950) Basal metabolic rates and physical fitness scores of British and Indian males in the Tropics. J. Physiol., 110: 356.

43. NIYOGI, S.P., PATWARDHAN, V.N. and MORDECAI, J. (1939) Studies on basal metabolism in Bombay. Ind. J. med. Res., 27: 99.

44. ORR, J.B. and KINLOCH, J.P. (1921) Note on the influence of diet on the energy expenditure in work. J. Roy. Army Med. Cps. 36, 81.

45. ORR, J.B. and LEITCH, I. (1938) The determination of the calorie requirements of man. Nutr. Abstr. Rev., 7: 509.

46. ORSINI, D. and PASSMORE, R. (1951) The energy expended carrying loads up and downstairs. Experiments using the Kofranyi-Michaelis Calorimeter. J. Physiol., 115, 95.

47. PASSMORE, R. and THOMSON, J.G. (1950) Energy expenditure during stepping. Brit. J. Soc. Med., 4, 234.

48. PRIESTLEY, J. (1779) Experiments and observations on different kinds of air. Vol. 1, 92. Johnson.

49. QUENOUILLE, M.H., BOYNE, A.W., FISHER, W.B. and LEITCH, I. (1951) Commonwealth Bureau of Animal Nutrition, Tech. Comm. No. 17.

50. RABINOWITCH, I.M. and SMITH, F.C. (1936) Metabolic studies of Eskimos in the Canadian Eastern Artic. J. Nutr., 12, 337.

51. RAHMAN, S.A. (1936) The basal metabolism of young men at Hyderabad (Deccan) with a study of their physical characters. Ind. J. med. Res., 24, 173.

52. RAJAGOPAL, K. (1938) The basal metabolism of Indian and European men on the Nilgiri Hills (S. India). Ind. J. med. Res., 26: 411.

References contd.

53. ROBERTSON, J.D. and REID, D.D. (1952) Standards for the Basal Metabolism of normal people in Britain. Lancet, 1: 940.

54. RUBNER (1894) Z. Biol., <u>xxx</u>, 73, quoted by Lusk.

55. Shorter Oxford English Dictionery (1950)

56. SOKHEY, S.S. and MALANDKAR, M.A. (1939) Basal metabolism of Indians. A study based on the examination of sixty normal Indian men. Ind. J. med. res., <u>27</u>: 501.

57. STEGGARDA, M. and BENEDICT, F.G. (1932) Metabolism in Yucatan: a study of Maya Indians. Amer. J. Physiol., <u>100</u>, 274.

58. TURNER, A.H., and BENEDICT, F.G. (1935) Basal metabolism and urinary nitrogen excretion of Oriental women. Amer. J. Physiol., <u>113</u>: 291.

59. VOGELIUS, H. (1945) Basal metabolism of girls. Nyt Nordisk Forlag Arnold Busck. <u>1</u>: 617.

60. WILSON, E.A. (1945) Basal metabolism from a standpoint of racial anthropology. Amer. J. phy. Anthrop., <u>3</u>: 1.